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HARDENED WATER DELUGE SYSTEM FOR MELT/POUR PLANT

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20. ABSTRACT *(Continue on reverse side if necessary and identify by block number)*

Establishing the vulnerability of water deluge systems to blast and fragments is a continuing problem. Typically, the melt/pour facility at Lone Star Army Ammunition Plant (AAP) is contained in buildings which are interconnected by ramps. Transporting explosives through these ramps poses the threat of explosion on fire propagating from one building to another. Since such incidents can destroy conventional fire detection and protection systems,

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20. ABSTRACT (Continued)

this program was initiated to identify deluge systems capable of withstanding detonation without compromising their capability to extinguish secondary fires.

A series of scaled tests established the general magnitude of the threat; nozzles were chosen from water coverage tests; deluge tests demonstrated that deluge systems properly tuned to the ramp/conveyor configuration can extinguish explosive fires in a reasonable length of time, and the survivability of alternate hardened deluge systems was demonstrated.

The wide-spray nozzle proved to be more effective than the narrow-spray in maintaining water on the explosive at different water pressures and damage levels. The rate of application is affected by the degree of pressure and the amount of damage, and is particularly sensitive to the position of the nozzle with respect to the explosive. A small change in position significantly changes the water coverage. On-the-pad deluge systems would have difficulty surviving the blast and fragment environment; subsurface systems are needed.

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INTRODUCTION

The purpose of this program was to develop a hardened fire protection system for the 105-mm HE M1 projectile melt/pour facility at Lone Star Army Ammunition Plant. This hardened filed protection system is intended for use at the ends of ramps connecting the various process buildings at the facility. The purpose of the water deluge system is to prevent the spread of fire between buildings in accordance with the requirements of the DARCOM Safety Office. Hardened deluge systems were designed to survive blast and fragment effects associated with (1) an explosion in one of the several buildings, and (2) explosions within any of the ramps connecting the buildings.

The program objectives were as follows:

1. Design and build a hardened water deluge system for each of the three ramp configurations.

2. Perform tests to prove and refine the hardened water deluge system. These included tests to evaluate water coverage, extinguishment time for Composition B fires, and survivability of a hardened water deluge system against an accidental explosion.

The objectives were accomplished in an iterative manner. Information obtained from tests was used to further improve the original design of the hardened water deluge system; thus, the final design of the hardened water deluge system was not determined until the testing program was completed.

To accomplish the above objectives, the following program was conducted:

1. A preliminary hardened deluge system was designed and built. This design was based on previous experience in which deluge systems were successfully used to combat M1 propellant and lead azide fires (Refs 1 and 2). Also, the water pressure limits of 372-kPa residual at Lone Star AAP were considered.

2. Calculations were made to assess blast and fragment lethality from accidental explosions at Lone Star AAP.

3. Scaled tests, simulating accidental explosion of Buildings E-161, E-125, E-120 or E-123, were conducted to evaluate fragment and blast damage against scaled

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hardened deluge models. The scale models simulated deluge system characteristics pertaining to blast and fragment resistance.

4. Tests to evaluate water coverage of the deluge system were conducted. From these tests, the best nozzle type and nozzle configuration were chosen and implemented into the deluge system.

5. Tests were conducted to determine extinguishment time of Composition B fires on simulated portions of Ramps RE-25 and Re-42 or Re-43.

6. Full-scale tests were conducted to determine functioning of deluge systems after accidental explosion of Composition B inside Ramps RE-25, RE-42 or RE-43, and Re-27 or RE-28.

EXPERIMENTAL PROGRAM

Description of Melt/Pour Facility

The melt/pour facility at the Lone Star AAP consists of four distinct operations. Each operation occurs in a separate building and is connected with the succeeding operation by a ramp which is housed in a tunnel-like structure. The tunnel housing of the three ramps connecting the four operations is essentially the same - a concrete floor supporting I-beam steel girders which are covered with Alcoa aluminum V-beam (Ref 3) siding. The ramps contained within these tunnels are quite different for each of the three in-line processes. These ramps are as follows:

Ramp RE-25

This ramp connects Building E-161 to Building E-125 and is used to transport boxes of Composition B from the receiving building to the unpacking building. The ramp is approximately 3 meters wide by 3 meters high by 120 meters long. Boxes containing 27.2 kilograms of Composition B are transported to the unpacking building on the lower portion of a double roller conveyor. Empty boxes are returned to the receiving building on the upper level. Boxes are spaced at a minimum safe separation distance of 3.66 meters such that propagation of a high order detonation from one box to the next will not occur. Conversely, however, it is conceivable that a fire could be propagated along the enclosed ramp, eventually reaching the next building in the process line. Hence, the intention of the program was to design a water deluge system capable of sustaining the initial blast and fragments from an explosion in one of the buildings, e.g., Building E-161, and still be able to extinguish a propagating fire and prevent this fire from reaching the next building, Building E-125; or to survive the detonation effects from one box of Composition B and extinguish, or prevent the spread of any secondary fires. The water deluge system had to be designed to apply water on the boxes of explosives without interference from the conveyor line structure.

Ramps RE-42 and RE-43

These two ramps are similar parallel ramps which transport the loose, flaked Composition B explosive

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from the unpacking operation in Building E-125 to the melt/pour operations in Buildings E-120 and E-123. These two ramps are housed in the same type of tunnel-like structure; however, these ramps are unique in that loose, flaked explosive is transported on a Serpentix conveyor belt. To allow for the extraction of dust, which is generated in the transport of loose explosive, the conveyor belt is covered with a loose fitting hood which presented a problem in designing a water deluge system to effectively extinguish a fire on the conveyor line.

Ramps RE-27 and RE-28

Again, there is a situation of two parallel ramps conveying loaded 105-mm HE shells from the melt/pour facility to the cooling station, Buildings E-129 and E-130. In these two ramps, the loaded explosive shells are being transported on wheeled buggies, each buggy containing 16 shells in a 4 x 4 configuration. In order to maintain temperature control during this transport operation, the buggies are moved along an inner tunnel housed within the standard tunnel configuration. This inner tunnel is a steam shield constructed of 16-gauge steel covered with a 25.4-mm thick insulating material. Again, this configuration posed a unique situation for the design of a water deluge system that can survive the effects of a detonation of the projectiles on one of the buggies and successfully contain any secondary fires within the ramp.

Design and Construction of the Hardened Water Deluge System

The steps in designing a deluge system have been elaborated upon in a previous research effort (Ref 1) involving alcohol-lead azide fires. The first step in the design of a deluge system is to determine the flammable materials present and the burning rates of these materials. At Lone Star AAP, Composition B is present in large quantities at various locations in the plant. These locations are connected by ramps. There is danger of flame propagation from one building to the next via the ramp network. A deluge system is necessary to prevent possible flame propagation. Since Composition B is a high explosive, it is possible to have accidental explosions anywhere in the plant or in the ramps. Composition B, throughout the ramp network, is placed at "safe separation" distances such that explosive propagation will not occur through a ramp. However, an

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accidental Composition B explosion can initiate secondary fires which could then conceivably propagate through the network and thus the whole plant system. A deluge system is needed which remain functional after the blast and fragments effects from an accidental explosion of Composition B.

A fire involving high explosives requires rapid detection and activation of the water deluge system. From previous research experience (Ref 1), an ultraviolet detection system was deemed most reliable. In all tests involving Composition B fires of explosions, the fire detector system used was the Det-Tronics DE-R 7300A Controller and the C 7037B Detector. This detector is sensitive to radiation in the 1,850- to 2,450-Angstrom (0.18 to 0.24) range and is insensitive to sunlight, incandescent and fluorescent lights. An equipment list is provided in Appendix B listing all major deluge system components.

After selecting the fire detection system, a suitable water distribution system had to be designed. Lone Star AAP has a nominal static water pressure of 448 kPa.

The Southwest Research Institute's Field Test Program used a 15,140-liter tank as a water supply. The water was pumped to the water deluge system using a Hale pump, Model 50 FB. The pump had a 127-mm suction line and a 102-mm discharge line, pumping at a maximum rate of 1,540 liters per minute at a distance of 70 meters from pump to test pad (see Fig 1). The flow of water was controlled by the use of an in-line Primac quick reaction valve manufactured by the Grinnel Company and located adjacent to the rear end of the test pad. This valve utilized two explosive primers (Hercules MK 131) to shear a holding pin, at which time the line water pressure forced open a valve to release the water. Static pressures were measured immediately upstream of the Primac valve and residual pressures with flow were obtained at the downstream end of the feeder line alongside the test pad. The line from the Primac valve to the water nozzles was not pre-primed with water because exposed water lines at the Lone Star AAP are not insulated against freezing temperatures.

Finally, the nozzle configuration has to be determined. All ramps for which a deluge system was designed at the Lone Star AAP are constructed essentially the same - a steel I-beam framework on a concrete slab with an aluminum V-beam siding. Deluge tests were conducted at the ballistics and explosives range at Camp Bullis, Texas, utilizing 9.14 meters of simulated ramp on a concrete slab. The ramp dimensions were 3.048 m by 3.048 m with a 38.1-mm x 38.1-mm x 3.18-mm angle iron framework and an Alcoa

aluminum V-beam siding, stucco embossed (1.06 m wide x 3.05 m long x 0.813 mm thick, 2.60 kg/m^2).

The ramp system at Lone Star AAP (See Fig 2) is used to convey Composition B in various forms from one building to another. A deluge system was designed such that it could be used in any of the three ramp configurations. They are: Ramp RE-25, with a double steel roller conveyor; Ramps RE-42 and RE-43, utilizing Serpentix conveyors with a dust exhaust head; and Ramps RE-27 and RE-28, used to transport 105-mm shells on pallets. Each of these ramp systems provides unique obstructions to water flow onto Composition B fires.

Ramps RE-27 and RE-28 pose the greatest threat to a deluge system in the event of an accidental ramp explosion. A pallet of sixteen 105-mm shells could explode, with a blast approximately equal to that from 43.5 kg of Composition B, and generate a large quantity of projectile fragments. Ramps RE-42 and RE-43 pose a minimal blast and fragment threat to a deluge system. The Serpentix conveyor system poses the greatest fire propagation threat. The dust exhaust hood over the Serpentix conveyor also serves as an obstruction to the water flow. Ramp RE-25, conveying 27.2 kg of Composition B in paper boxes, poses a threat from blast and conveyor fragments. Finally, the accidental explosion of Building E-161, E-125, E-120 or E-123 must be considered in designing a deluge system.

Nozzle type and configuration are of primary importance in a deluge system. It was designed to have one master nozzle design with possible minor modifications for all three tunnel configurations at Lone Star AAP. An initial nozzle pattern was chosen, based on previous deluge design experience. The initial hardened deluge system design, downstream from the Primac valve, was as follows:

1. All pipe was Schedule 40. The feeder lines were nominally 101.6-mm diameter. The riser lines to the nozzles were nominally 38.1-mm diameter. The distance between risers was 4.6 m.

2. For test purposes, the hardened deluge system had to be made so that adaptations could be made as needed. Also, for economic reasons, only 9.14 m of deluge system were simulated. A criss-cross spray pattern was utilized to obtain area coverage. The nozzle elevation, and thus the trajectory of the spray pattern, could be varied for obstacles in the water flight path.

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3. In Figure 16, the two furthest nozzles (at the right side of the photograph) were aimed at the point on the conveyor where the box of Composition B is located. This point was also the location at which density measurements were made during water coverage evaluation tests. Simulation of one sheared nozzle was accomplished by removing the nearest of these two nozzles, and simulation of two sheared nozzles by removing the pair of nozzles.

4. It was anticipated that blast and fragments could advesely affect the functioning of the deluge system. To provide as much protection to the deluge system as possible, the feeder lines would be placed outside the tunnel to allow the concrete slab to provide protection from blast and fragments.

5. Two types of armored deluge nozzle were to be evaluated: the Grinnel R-1-45-41 nozzle and the Spraying Systems Company's Veejet nozzle, Model No. 1-1/4U 15500.

TEST RESULTS

General

After design and fabrication of the hardened deluge system, the test program was begun. The test program was divided into three separate phases. The first phase investigated the survivability of the deluge system should one of the primary buildings explode. A combination of analysis and scale model testing was utilized. Tests were conducted to separately determine the effects of blast or fragments on the deluge system in case of an explosion of Building E-161, E-125, E-120 or E-123. A second phase involved the selection of the proper nozzle type and verification of original riser separation of 4.6 meters. This required tests to determine water application rates. Also, tests were made to determine whether the observed application rates would extinguish Composition B fires in the three different ramp configurations. Finally, full scale tests were made on a simulated section of a full scale ramp.

Scaled Tests

The effects of a catastrophic explosion of Building E-161, E-125, E-120 or E-123 was assessed in terms of deluge system survivability. Building E-161 contains up to 40,823 kg of Composition B, E-125 up to 1,361 kg, and both Buildings E-123 and E-120 up to 1,134 kg. The quantity of explosive involved in an explosion of any of the buildings dictated that experimental tests simulating an exploding building utilize scaled amounts of explosive. A model analysis was performed for the purpose of designing tests with properly scaled test parameters (Ref 4). Tests were designed to separately observe the effects of blast and fragments on the deluge system.

Scaled Blast Tests.

The blast from an explosion of one of the buildings could permanently deform the risers of the deluge system. The results would be (1) a change in trajectory of the water stream, (2) construction with reduced flow, or (3) rupturing of the pipe.

Calculations were made to assess the blast severity at Ramps RE-25, RE-42, RE-43, RE-27 and RE-28, should Buildings E-161, E-125, E-120 or E-123 explode. Two blast parameters were evaluated: side-on overpressure and side-on impulse. The complex geometry of the explosive within the buildings, and the presence of obstacles and sources of confinement make exact

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calculations of blast parameters at close stand-off difficult. Fortunately, at the stand-off of importance for the deluge system blast evaluation, fairly reasonable computations can be made using simplifying assumptions. In this frame of thinking, the assumptions were made that the Composition B in each building at Lone Star AAP is spherical in shape, bare and at ground level.

The procedure used in the calculations was as follows:

1. Distances were measured from center of explosion (in all cases assumed to be center of building) to closest end of deluge system being considered at another building.

2. The maximum possible explosive weight was considered for each case; e.g., Building E-161 contains a possible 40,823 kg of Composition B.

3. The maximum mass of Composition B for each building as converted to equivalent masses of TNT for comparison to TNT data, by the relation:

Equivalent mass of TNT

$$= (M_{TNT/E})(M_{Comp\ B})/(M_{Comp\ B/E})$$

$$= 1.148\ M_{Comp\ B} \qquad\qquad (Ref\ 4)$$

where:

$M_{TNT/E}$ = mass per unit energy of detonation of TNT

$M_{Com\ B/E}$ = mass per unit energy of detonation of Composition B, and

$M_{Com\ B}$ = the mass of Composition B.

4. These "equivalent" masses of TNT were then doubled because the explosions to be considered were not free air blasts and could possibly (worst case) produce the effects of twice the explosive charge involved, provided the ground was a perfect reflector of blast waves.

5. From TNT data curves for air blasts, peak side-on overpressure and side-on impulse were obtained for each building, consisting of an explosive weight and a stand-off distance.

Table 1 presents the calculated parameters. In order of listing are: Condition indicating where the explosion occurs and the building at which the blast effects are being considered, the mass of Composition B in the exploding building, the closest distance between the exploding building and the deluge system protecting the adjacent building at which blast parameters are being evaluated, the peak side-on overpressure, the side-on impulse, and the scaling factor to use in scaled blast and fragment tests. Note from Table 1 that the most severe blast effects possible at any deluge system occur should Building E-161 explode. Peak side-on overpressure ranges from 13.8 to 172.3 kPa and side-on impulse varies from 0.379 to 4.067 kPa/sec. Field tests were conducted to determine the effects of blast and fragments upon the proposed deluge system. Because the amount of explosive involved in actual accidental explosions (up to 40,823 kg of Composition B) is too large for testing purposes, scaled amounts were used. In principle, any amount of explosive can be used. However, in the interests of economy and personnel safety, it was desired to limit the explosive mass in scale tests to 45.36 kg. Fixing the scaled mass to a single value uniquely determines the magnitude of the remaining parameters in an experiment. The Hopkinson Scaling Law was utilized to determine the proper magnitude of the pertinent parameters in the scale tests.

The Hopkinson Scaling Law is:

$$R_{F.S.}/W_{F.S.}^{1/3} = R_T/W_T^{1/3}$$

A scale factor, λ, is defined as:

$$\lambda = W_T^{1/3}/W_{F.S.}^{1/3} = R_T/R_{F.S.}$$

where,

$R_{F.S.}$ = the full scale stand-off

$W_{F.S.}$ = the full scale explosive mass

R_T = the scaled stand-off for tests

W_T = the scaled explosive mass for tests

λ = the scale factor.

Three different accidental explosions were analyzed:

Building E-161:

$W_{F.S.}$ = 40,823 kg

W_T = 45.36 kg

λ = 0.104 $\approx$ 1/10.

Building E-125:

$W_{F.S.}$ = 1,361 kg

W_T = 45.36 kg

λ = 0.322 $\approx$ 1/3.

Buildings E-120 and E-123:

$W_{F.S.}$ = 1,134 kg

W_T = 45.36 kg

λ = 0.342 $\approx$ 1/3.

It is important to recognize the significance of the scaling factor, λ. The scale factor dictates the proper magnitude of different test parameters necessary for similarity between the full scale and model explosions. Table 2 shows the test parameters considered and the functional relationship between full scale and scaled values.

The relationships shown in Table 2 between full scale and scaled parameters are valid only if the following restrictions hold between the scaled and the full scale accident scenario:

1. Tests are conducted under identical atmospheric conditions.

2. Same type explosive is used.

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3. Charge geometries and geometries of objects in the blast field (example - building location, deluge location) are the same.

Finally, to maintain similarity, it is necessary to scale gravity. Since this cannot be done at the test facility, the results of the scale tests have to be interpreted with the consideration that gravity is not scaled. The result is that fragments generated in the scale tests will fly as far as fragments in the full scale tests, instead of the expected scaling of the flight distance by a factor of λ.

Static load tests were conducted on the proposed deluge riser nozzle assembly, to determine which component of the riser-nozzle assembly would yield first under equivalent torque. It was found that the riser yielded first; i.e., under the least torque, at the point where the riser connects to the feeder line. This factor simplified the construction of a model nozzle-riser assembly. Two different scale (1/3 and 1/10) models were designed and built. The model riser-nozzle assembly was built of steel of the same strength as the full scale riser-nozzle assembly. Four parameters were scaled to assure similarity of the scale model to the full scale model: pipe wall thickness at the region where the pipe failed, presented area of the riser-nozzle assembly, second moment of area, and mass of riser-nozzle system. The designs of the 1/3- and 1/10-scale model riser and nozzle assemblies are as presented in Appendix A. Figure 3 contrasts the full scale riser-nozzle assembly which was modeled to the 1/3- and 1/10-scale models. The model assemblies appear dissimilar to the full scale system, yet accurately model the parameters required to maintain similarity.

With the combined use of two different scale models, and by varying the scaled stand-off distance, many of the full scale explosion conditions could be simulated in one test. A total of three tests, each utilizing 45.4 kg of Composition B, were conducted to evaluate the blast and fragment effects on the deluge riser-nozzle assembly. These three tests simulated 18 blast and fragment conditions. Not every condition listed in Table 1 was actually tested in the field. Instead, only selected worst cases were tested. For example, in the case where Building E-161 explodes, the "worst case" condition which was tested was the deluge system at the entrance port to Building E-125. If the deluge system survives at this location, survival should be insured at all less severe conditions involving the explosion of Building E-161. This criteria was applied to all blast conditions listed in Table 1.

Figures 4 through 13 are sketches of the scaled test setups. A 1/10-scale model of a 9.1-m section of Ramp RE-25 was constructed and placed 4.7 meters from the center of a 45.4-kg Composition B charge. Also, a 9.1-m full scale simulated section of Ramp RE-25 was located 4.7 meters from the 45.4-kg charge and 90° from the scale ramp section (see Figs 4 and 5). The water deluge system was emplaced in the full scale system. Fragment screens with 1/10-scale fragments (up to 25-mm diameter maximum) were placed 1 meter from the charge center to simulate typical fragmentation associated with Building E-161. Pressure gages were placed 4.7 and 9.5 meters from the charge center for measurement of blast side-on overpressure. Figure 5 shows the full scale section of simulated Ramp RE-25. The deluge system is still intact and operable after the test. It can be observed that the explosion of Building E-161 would certainly destroy Ramp RE-25. The scale model Ramp RE-25 is presented in Figure 7. The side-on overpressure histories of the blast tests are presented in Figures 8, 10 and 11.

The next step in assessing the blast threat to the deluge system, in the event that a building explodes, is to test the scale models. Tests 3 and 4 (see Figs 9 and 13) evaluated the scale model riser-nozzle assemblies, utilizing a 45.4-kg Composition B charge at various stand-offs. Figure 12 is the 1/3-scale model riser-nozzle assembly after a test; there is little evidence of blast damage. After each test, each model riser-nozzle assembly was placed on a plane table and the amount of plastic (permanent) deflection was measured. Table 3 summarizes the results of the blast tests on model deluge riser-nozzle assembly systems. A maximum allowable deflection (plastic deformation of riser-nozzle assembly) was chosen to be 5°. This corresponds to a deflection of the trajectory of the water stream at the target (conveyor system) of 150 mm. The maximum deflection angle recorded was 3.6°. Hence, it can be concluded that the blast associated with the explosion of Building E-161, E-125, E-120 or E-123 would not critically affect the deluge systems at adjacent buildings.

Scaled Fragment Tests

The explosion of Building E-161, E-125 or E-123 would generate a large number of fragments which could possibly destroy the deluge system at an adjacent building. Fragments can damage a deluge system in the following modes: (1) small high velocity fragments can perforate or shear a water supply line; and (2) large, low velocity fragments (i.e., I-beam) can shear or bend a water pipe upon impact, changing water trajectory or causing a restriction of water flow.

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A similar approach to that utilized in assessing blast severity was conducted to determine the lethality of fragments generated by the explosion of Building E-161, E-125, E-120 or E-123. A large fragment can damage a deluge system even at very low striking velocities; e.g., a large fragment is lethal to a deluge system over its entire flight path. Hence, all one needs to do is to find the maximum range of large fragments to determine the lethality range. The maximum ranges of large fragments were calculated for large fragments emanating from Buildings E-161 and E-125. Two typical large fragments were considered: I-beams of dimensions 203 mm x 152 mm x 53.5 kg/m, 366 m long with mass of 196 kg and 305 mm x 305 mm x 305 mm concrete blocks, with a mass of 65 kg.

Table 4 lists the results of the calculations (Ref 7). Listed are: donor building, explosive charge mass, type of fragment, dimensions and weight of fragment, initial velocity of fragment, maximum range of fragment, and minimum steel shield thickness needed to stop the fragment. The following procedure was used in calculating maximum fragment ranges:

1. Explosive is considered to be at the center of the building.

2. I-beams were explosively loaded with initial shock and drag to obtain an initial velocity.

3. Concrete blocks were explosively loaded with initial shock to obtain an initial velocity.

4. Trajectory angle was chosen to give maximum range.

From Table 4, it can be concluded that large fragments generated in the explosion of Building E-161, E-125, E-120 or E-123 would be within range and capable of destroying the deluge system to the neighboring building.

Scale model tests involving fragments were conducted to determine the penetration potential of fragments generated by a building explosion. The test arrangement is illustrated in Figure 13. The test matrix and results are listed in Table 5. Steel sheets, with thickness corresponding to the scale factor times twice the deluge riser pipe thickness, were placed at scaled stand-offs from 45.5-kg Composition B charge. Around the Composition B charge were placed scaled fragments up to 305 mm in diameter. The steel plates represented the exposed deluge riser-nozzle assembly in terms of total steel thickness which a fragment would engage. From Table 4, it can be seen that the

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steel plate targets were perforated by scaled fragments up to a full scale stand-off of 244 meters.

In conclusion, the explosion of Building E-161, E-125, E-120 or E-123 would pose little threat in terms of blast effect upon a deluge system at an adjacent building. However, the fragments generated by such an explosion are capable of destroying the deluge system at an adjacent building. The fragment density pattern must be determined to assess the actual fragment threat.

Water Coverage Evaluation

The ultimate goal of a water deluge system is to distribute large amounts of water within a given region in which the fire or fire propagation potential exists. A hardened deluge system not only has to survive blast and fragment effects but also has to apply water in sufficient amounts where needed. Therefore, the following tests were conducted:

1. To determine water distribution in terms of water flow rate/unit area.

2. To determine response of deluge system to Composition B fires in simulated sections of Ramps RE-25, RE-42 or RE-43.

In the first test, two different nozzles were evaluated and the nozzle providing the best coverage for a given ramp configuration was incorporated into the final deluge design. Also, the degraded performance of the deluge system, should a nozzle be sheared by blast or fragments, was determined. In the second test, extinguishment times were also determined should a nozzle be sheared by blast or fragments.

Water Coverage Tests

Water coverage tests were conducted using a simulated section of Ramp RE-25 (Fig 16). The data obtained are presented in Table 6. The water flow rate was measured at a representative region of the double roller conveyor system in Ramp RE-25 at residual pressures ranging from 82.7 to 379.2 kPa. The effects of water coverage with up to two sheared nozzles were measured.

Water coverage tests were conducted with both Veejet and R-1-45-41 nozzles. From the test data, the R-1-45-41 nozzle provided superior water coverage; hence, it was chosen as the nozzle to be used for the water deluge system.

Fire Extinguishment Tests

After selecting the best type of nozzle and incorporating it into the deluge system design, tests were conducted to evaluate the ability of the deluge system to extinguish Composition B fires which could occur in Ramps RE-25, RE-42 and RE-43. Figures 16 to 21 illustrate the test setup and typical results for simulated sections of Ramps RE-25 and RE-42/43. The cardboard box on the steel roller conveyor was filled with 4.5 kg of Composition B and ignited with an electric match placed approximately 20 mm below the Composition B surface. An oscilloscope was used to record the response of the deluge system after ignition of the Composition B in the cardboard box. Figure 17-A presents a record of the typical response. All traces begin at the moment the electric match is ignited. Three traces were visible:

1. The delay to fire detection by the UV detector system.

2. The delay to activation of the Primac valve, and

3. The delay to actual flow of water out of the nozzles.

Similar tests were conducted using a simulated section of Ramps RE-42/43 (Figs 20 and 21). The Composition B was ignited utilizing an electric match placed 20 mm below the surface. Figure 17-B presents a typical record of the deluge response. All three times begin at the moment the electric match is ignited. The data obtained from the extinguishment tests are listed in Table 7 and 8. The recovered weights of Composition B give a measure of the success of the deluge system.

The average extinguishment time for Composition B fires in the Ramp RE-25 configuration was 36 seconds and for Composition B in the Ramp RE-42/43 configuration was 25 seconds. Tests were also conducted in which one and then two sheared nozzles were simulated by unscrewing the nozzles. It was found that for the Ramp RE-25 configuration, Composition B burned to completion with one sheared nozzle. In the Ramp RE-42/43 configuration, up to two sheared nozzles would still allow extinguishment to occur in an average of 44 seconds.

In summary, the deluge system provides a water flow rate/unit area of 24.37 LPM/m^2 to the region where fires are

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expected to occur. Also, Composition B fires occurring in either the RE-25 or RE-42/43 configuration were successfully combatted.

Full Scale Tests

An accidental explosion could possibly occur in Ramp RE-25, RE-42/43 or RE-27/28. Cardboard boxes filled with 27.2 kg of loose, flaked Composition B are transported in Ramp RE-25. Ramps RE-42/43 each transport loose, flaked Composition B via a Serpentix conveyor, each conveyor "pan" containing 0.9 kg. Sixteen 105-mm shells with risers, each shell and riser filled with molten Composition B, are transported via pallets with a worm gear and steel track drive system. The explosives are placed at a "safe separation" distance, all but eliminating explosive propagation down the conveyor line. However, the deluge system must remain operable to quench secondary fires associated with the accidental detonation.

In the initial design of the deluge system, the feeder lines were placed outside the ramps to provide the added protection of the concrete slab against blast and fragmentation. However, this imposed the use of a "dry line" system due to freezing temperatures experienced at Lone Star AAP. It was desired to place the feeder line inside the ramp systems, if at all possible. A full scale test (Test 6) was conducted with a simulated section of Ramp RE-25 (without tunnel frame) and a "mock" feeder line, 9.14 meters long, placed on the slab parallel to the steel roller coveyor system. An operational deluge system was placed outside the ramp with the concrete slab affording it protection. The "mock" feeder line was firmly clamped at the ends. A 27.2-kg cardboard box of Composition B was placed at the center of the length of the roller conveyor. Figure 22 illustrates the results of the test. The mock feeder line was severely bent, with several fragment impact marks visible. The operational deluge system placed outside the ramp remained intact, but was rotated about 90° due to impact by the mock feeder line. An immediate conclusion is that a feeder pipe inside the ramp would need shielding.

A second full scale test (Test 70) involved a simulated section of Ramps RE-42/43. A 3.05-m x 3.05-m x 9.14-m long tunnel was constructed out of an angle iron (38.1-mm x 38.1-mm x 3.18-mm) with aluminum V-beam siding. A Serpentix conveyor was loaded with 26.31 kg of Composition B, 0.9 kg per conveyor pan. A deluge system was placed outside the ramp. The purpose of the test was to determine the extent of damage to the ramp and to determine whether the deluge system could successfully combat any residual Composition B fires. A 50-gram C-4 booster with an

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electrical blasting cap (M6) was placed in a Serpentix pan in the center of the ramp. The Composition B in the pan detonated, but neither fire nor the detonation propagated down the conveyor. The explosion caused the V-beam aluminum panels to collapse onto the hood over the Serpentix conveyor system, preventing proper water coverage by the water deluge system. The water deluge system survived the blast and functioned properly in terms of fire detection and Primac valve activation (see Figs 23 and 24).

The full scale tests (Tests 71 and 72) were conducted with simulated sections of Ramp RE-27/28. The standard 3.05-m x 3.05-m x 9.14-m tunnel was constructed out of angle iron 38.1 mm x 38.1 mm x 3.18 mm and aluminum V-beam siding. The blast from 16 (105-mm) projectiles detonating at once represents the most severe conditions to be experienced from a detonation inside a ramp. Hence, if the deluge system would survive these tests, it should survive all less severe ramp explosion cases. Three deluge system designs were evaluated in Test 71. Two mock deluge systems were placed inside the ramp, each with a different type of shielding. The test setup is illustrated in Figure 25. One deluge system inside the ramp had its feeder line shielded by having a larger 152-mm diameter pipe place concentrically about the feeder line, with holes cut into the shield pipe to allow risers to attach to the feeder pipe. This design was termed "pipe-in-pipe" configuration. The pipe was secured at 0.91-meter intervals to the concrete floor. A second deluge design used inside the ramp utilized curbing as shields. The curb sections were secured with bolts in front of the feeder line. The feeder line was also secured every 0.91 meter with bolts drilled 80 mm into the concrete. The initial deluge design was the third deluge system; it was placed outside the ramp to obtain shielding provided by the concrete slabs. Sixteen 105-mm shells with risers filled with 0.45-kg loose flaked Composition B were placed in the center of the ramp. A 50-gram C-4 booster with an M-6 electric blasting cap was placed in one of the 105-mm risers. Figures 26 to 32 illustrate the results of the test. The deluge system, protected with a concentric pipe around the feeder pipe, was projected 79.2 meters from the concrete pad. The feeder pipe was severely bent and perforated as can be seen in Figures 29 and 30. From distance measurements of where the pipe first struck the ground after the explosion, it has been calculated that the initial velocity of the pipe was at least 30.5 m/sec and possibly as great as 60 m/sec. All risers on the feeder pipe were sheared. The deluge system shielded by the curbing was badly damaged. A section of the feeder line was destroyed as well as one curb section. The remainder of the line, however, was lying on the concrete slab. The dummy nozzles were perforated. The deluge system placed outside the ramp also had all of the nozzles

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sheared or perforated. The feeder line, however, was intact after the blast. Figures 31 and 32 give views of the damage to the deluge system. From the results of this test, it was apparent that a deluge system inside the ramp was not feasible.

Test 72 was a repetition of Test 71 with only the deluge system outside the ramp being tested. Also, the deluge system was lengthened to determine the survivability of riser-nozzle systems at a larger stand-off from the cart. Six riser-nozzle assemblies were used in the test. The radial distances from the charge center were 1.5, 3.6, 4.9, 5.5, 10.1 and 13.2 meters, respectively. Sixteen 105-mm projectiles with risers filled with 0.45-kg Composition B were placed in the center of the ramp, and were initiated with a 50-gram C-4 booster and M6 electric blasting cap. A 25.4-mm thick x 1.83-m x 2.44-m mild steel plate was placed 12.2 meters from the 105-mm projectile cart as a witness.

The purpose of the steel witness plate was to assess fragment lethality (Fig 33), should it later be necessary to provide shielding for the deluge system. The maximum penetration observed in the steel plate was 20.3 mm. Figure 34 is a view of the test setup. Figures 35 to 38 illustrate each of the riser-nozzle assemblies used, except the riser-nozzle assembly at a 1.5-m radius which could not be located.

From test results, it was observed that the accidental explosion of a pallet of 105-mm shells with risers poses the greatest threat to a deluge system. Calculations were made to assess the blast field produced by the explosion of a pallet of 105-mm shells. The amount of Composition B contained in sixteen 105-mm shells with risers is about 45.4 kg. The following assumptions were used in calculating the maximum side-on overpressure: bare charge, i.e., no energy lost in fragmentation process and the ground is a perfect reflector of blast waves. The results of the calculations are as shown in Table 9.

Figure 39 is a plot of side-on overpressures vs. stand-off for the explosion of 45.4 kg of Composition B.

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CONCLUSIONS

Using accumulated data and test results, several conclusions have been rendered as follows:

1. Composition B fires can be extinguished, utilizing the deluge system as previously described, in approximately 0.5 minute, provided the deluge system is properly positioned.

2. The water coverage provided by the deluge system is sensitive to line pressure and position of system relative to extinguishment area.

3. The deluge system must be protected from blast and fragments produced by accidental explosions, by utilizing steel shields and/or by placing the deluge system below ground.

RECOMMENDATIONS

Based on the aforementioned conclusions and pertinent data, the following recommendations have been prepared for presentation:

1. The deluge system should be below ground level and all exposed members shielded. It was found from tests in which 105-mm shells were detonated that at least 25-mm thick steel shields are required to prevent fragment perforation.

2. Each deluge system should be implemented with rate of flow controller valves to limit pressure loss in the supply main in the event of a deluge line rupture.

3. To allow the shortest possible extinguishment time, boxes of Composition B on Ramp RE-25 should have lids removed.

4. In the event of fire, the dust exhaust hoods on Ramps RE-42/43 should be at least 150 mm above the Serpentix conveyor to allow a water stream to enter for fire extinguishment.

5. The deluge system must be positioned after installation so as to provide maximum water coverage; i.e., the system must be "tuned". This is accomplished in the melt/pour facility by actual water coverage tests, after installation of the deluge system, to obtain proper positioning of the deluge system for optimum water coverage.

REFERENCES

1. GEHRING, J.W., "Design of a Deluge System to Extinguish Lead Azide Fires", Southwest Research Institute, Report prepared for ARRADCOM, Dover, N.J., Contract No. DAAA-21-76-C-0255, July 1978, in press.

2. GEHRING, J.W., "Development of a Water Deluge System to Extinguish M-1 Propellant Fires", Southwest Research Institute, Report prepared for ARRADCOM, Dover, N.J., Contract No. DAA-21-76-0255, August 1977, in press.

3. Aluminum Construction Manual, The Aluminum Association, New York, N.Y., August 1959.

4. BAKER, Wilfred E., WESTINE, Peter S., and DODGE, Franklin T., Similarity Methods in Engineering Dynamics, Hayden Book Co., Inc., Rochelle Park, N.J., 1973.

5. BAKER, Wilfred E., Explosion in Air, University of Texas Press, Austin, Texas, May 1973.

6. HOPKINSON, B., British Ordnance Board Minutes 13565, 1915.

7. BAKER, Wilfred E., KULESZ, J.J., RICKER, R.E., BESSEY, R.L., WESTINE, P.S., PARR, V.B. and OLDHAM, G.A., "Workbook for Predicting Pressure Wave and Fragment Effects of Exploding Propellant Tanks and Gas Storage Vessels", NASA CR-134906, Contract NAS3-19231, November 1975.

Table 1. Blast assessment of accidental explosion of Composition B in buildings at Lone Star AAP 105-mm melt/pour facility

| Condition | | Weight of explosive (kg) | Minimum distance (meters) | Peak side-on overpressure (kPa) | Side-on impulse (kPa-sec) | Scaling factor |
Explosion occurs at	Effect considered at					
E-161	E-125	40,823	88	172.3	4.067	.104
E-161	E-120	40,823	222	27.6	1.724	.104
E-161	E-123	40,823	183	41.4	2.137	.104
E-161	E-129	40,823	271	20.7	1.448	.104
E-161	Junction*	40,823	244	27.6	1.654	.104
E-125	E-161	1,361	95	20.7	0.448	.322
E-125	E-120	1,361	109	13.8	0.379	.322
E-125	E-123	1,361	81	20.7	0.510	.322
E-120	E-125	1,134	112	13.8	0.331	.342
E-120	E-129	1,134	73	27.6	0.496	.342
E-120	Junction*	1,134	43	62.0	0.827	.342
E-120	E-123	1,134	57	41.4	0.627	.342
E-123	E-125	1,134	85	20.7	0.434	.342
E-123	E-129	1,134	73	27.6	0.496	.342
E-123	Junction*	1,134	43	62.0	0.827	.342
E-123	E-120	1,134	43	62.0	0.827	.342

*Junction of RE-27 and RE-28.

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Table 2. Functional relationship between full scale
and scaled values

Paramater	Symbol	Full scale value	Scaled value
Charge weight	W	W	$\lambda^3 W$
Characteristic charge dimensions	d	d	λd
Height of explosive off ground	h	h	λh
Stand-off distance from explosion	R	R	λR
Characteristic dimensions of objects in blast field	l	l	λl
Shape factor for objects in blast field	l_i	l_i	l_i
Ratio of specific heats in air	γ	γ	γ
Speed of sound in air	a_0	a_0	a_0
Atmospheric pressure	p_0	p_0	p_0
Blast overpressure	p	p	p
Specific impulse	I	I	λI
Separation distance between explosive and potential fragment sources (walls, equipment, etc.)	S_i	S_i	S_i
Density of explosive	ρ	ρ	ρ
Fragment velocity	u	u	u
Acceleration due to gravity	g	g	g/λ
Applied torque to deluge nozzle/riser assembly necessary to effect permanent deformation	T	T	$T\lambda^3$

Table 2. Functional relationship between full scale
and scaled values (concluded)

Paramater	Symbol	Full scale value	Scaled value
Second moment of area of deluge nozzle/riser assembly	J	J	$\lambda^4 J$
Mass of deluge nozzle/riser assembly	M	M	$\lambda^3 M$

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Table 3. Blast tests on model deluge system

Condition			Scaled stand-off distance (meters)	Nozzle deflection angle (degrees)
Explosion occurs at	Effect considered at	Scale factor		
E-125	E-123	0.322	26.12	0
E-120	E-123	0.342	19.51	0
E-120[a]	Junction RE-27 & RE-28	0.342	14.60	1.5 3.6 0.3 0
E-161	Junction RE-27 & RE-28	0.104	25.24	0
E-161	E-123	0.104	18.93	1.5
E-161[b]	E-125	0.104	9.11	2.7

[a]Four tests conducted at this most severe case involving 1/3-scale models (explosions up to 3,000 lb Composition B).
[b]"Worst" case involving explosion of Building E-161.

Table 4. Results of building fragment calculations

Donor building	Mass of Comp B (kg)	Fragment description	Fragment mass (kg)	Initial velocity (meters/sec)	Maximum range (meters)
E-161	40,823	I-beam 152.4 mm x 203.2 mm, 3.05 m long	196.0	52.5	308
E-161	40,823	Concrete block 30.5 x 30.5 x 30.5 cm	65.8	52.1	233
E-125	1,361	I-beam 152.4 mm x 203.2 m, 3.05 m long	196.0	26.0	75
E-125	1,361	Concrete block 30.5 x 30.5 x 30.5 cm	65.8	36.5	121

Table 5. Fragment impact tests on steel sheets

Condition		Full scale stand-off (meters)	Full scale explosive weight (kg)	Scale factor	*Perforation into steel sheets (scaled riser thickness)
Explosion occurs at	Fragment impact considered at				
E-120	E-125	111.86	1,134	0.342	-
E-125	E-123	81.08	1,361	0.322	+
E-120	E-123	57.00	1,134	0.342	-
E-120	Junction RE-27 & RE-28	42.67	1,134	0.342	+
E-161	Junction RE-27 & RE-28	243.84	40,823	0.104	+
E-161	E-123	182.88	40,823	0.104	+
E-161	E-125	88.09	40,823	0.104	+

* + Target perforated by fragment.
  - Target hit but not perforated by fragment.

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Table 6. Evaluation of water coverage for deluge system at Ramp RE-25

Evaluation of Veejet nozzles

Test No.	Nozzle configuration[a]	Static pressure (kPa)	Residual pressure (kPa)	Water[b] collected (ml)	Water coverage (LPM/m²)
7	[A]	448	379	100	9.75
8	[A]	414	345	150	14.62
9	[A]	345	290	150	14.62
10	[A]	276	221	50	4.87
11	[A]	207	158	150	14.62
12	[B]	448	276	40	3.90
13	[B]	414	241	50	4.87
14	[B]	345	221	45	4.38
15	[B]	276	172	25	2.44
16	[B]	207	152	70	6.82
17	[C]	448	207	20	1.95
18	[C]	414	193	50	4.87
19	[C]	345	152	10	0.97
20	[C]	276	124	50	4.87
21	[C]	207	83	250	24.37

a[A] 9.14 meters of deluge system were tested using 4 nozzles.
[B] 9.14 meters of deluge system were tested using 4 nozzles, one nozzle removed to simulate a sheared nozzle.
[C] 9.14 meters of deluge system were tested using 4 nozzles, two nozzles removed to simulate sheared nozzles.

bWater collected for one minute in each test. Collection area was 0.01026 m².

Table 6. Evaluation of water coverage for deluge system at Ramp RE-25 (concluded)

Evaluation of R-1-45-41 nozzles

Test No.	Nozzle configuration[a]	Static pressure (kPa)	Residual pressure (kPa)	Water[b] collected (ml)	Water coverage (LPM/m²)
22	[A]	448	372	250	24.37
23	[A]	414	331	340	33.14
24	[A]	345	276	225	21.93
25	[A]	276	172	160	15.59
26	[A]	207	103	150	14.62
27	[B]	448	310	300	29.24
28	[B]	414	276	200	19.49
29	[B]	345	207	175	17.06
30	[B]	276	172	75	7.31
31	[B]	207	103	25	2.44
32	[C]	448	241	50	4.87
33	[C]	414	193	75	7.31
34	[C]	345	138	100	9.75
35	[C]	276	103	100	9.75
36	[C]	207	83	100	9.75

a[A] 9.14 meters of deluge system were tested using 4 nozzles.
[B] 9.14 meters of deluge system were tested using 4 nozzles, one nozzle removed to simulate a sheared nozzle.
[C] 9.14 meters of deluge system were tested using 4 nozzles, two nozzles removed to simulate sheared nozzles.

bWater collected for one minute in each test. Collection area was 0.01026 m².

Table 7. Fire extinguishment data - Ramp RE-25

Test No.	Number of nozzles	Residual pressure (kPa)	Time sequence (sec)				Mass of Comp B recovered (kg)	
			Fire detection[a]	Primac valve activation[a]	Water out[a]	Fire extinguishment[b]	Wet	Dried
38	4	372	1.35	1.4	1.4	23	4.5	-
39	4	372	2.0	2.25	2.3	19	4.6	-
40	4	372	15.4	15.6	15.75	142	2.8	-
41	4	372	16.85	16.9	17.1	11	-	-
42	4	372	24.5	-	-	11	4.5	-
43	4	372	38.0	-	-	15	4.1	-
44	4	372	29.0	-	-	16	3.6	-
45	4	372	55.5	-	-	43	3.2	-
67	4	276	22.0	22.1	22.29	c	0.2	0.2
68	4	372	19.0	-	19.54	c	0	0
66	3	310	26.8	26.92	26.99	c	0	0
64	2	241	24.0	24.83	26.09	c	0	0
65	2	241	20.8	21.37	21.46	c	0	0

Average Extinguishment Time: 35 sec using 4 nozzles at 372-kPa residual pressure.
Average Detection Time: 22.8 sec for above average extinguishment time.

aTime sequence T = 0 at ignition.
bTime from detection to extinguishment.
cFire not extinguished.

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Table 8. Fire extinguishment data - Ramp RE 42/43

Test No.	Number of nozzles	Explosive weight (kg)	Residual pressure (kPa)	Fire detection[a]	Primac valve activation[a]	Water out[a]	Fire extinguishment[b]	Mass of Comp B recovered (kg) Wet	Dried	Hood space (mm)
46	4	3.2	372	8.5	8.80	8.80	12	3.1	-	25
47	4	1.8	372	7.2	7.90	7.90	3	1.8	-	25
48	4	1.8	372	14.7	14.75	14.80	12	1.8	-	25
49	4	1.8	372	1.0	1.10	1.15	16	1.8	-	25
50	4	1.6	372	18.2	18.20	18.20	95	0.8	-	25
51	4	2.7	372	18.0	-	-	31	2.6	-	152
52	4	2.7	372	13.6	13.65	13.70	18	2.6	-	152
53	4	2.7	372	0.3	0.60	0.62	15	2.7	2.5	152
54	4	2.7	372	0.5	0.64	0.67	15	2.7	2.7	152
55	4	2.7	372	10.6	11.80	11.10	30	2.6	2.4	152
56	4	2.7	372	1.6	1.80	2.93	33	2.7	2.6	152
57	4	2.7	372	17.7	18.05	18.11	20	2.7	2.6	152
58	4	2.7	372	13.8	14.24	14.32	23	2.5	2.2	152
59	4	2.7	372	8.5	9.01	9.09	12	2.4	-	152
70	4	0.9	372	0.0	0.02	0.03	c	c	0	152
60	3	0.9	310	0.6	0.85	1.05	18	2.4	2.4	152
61	3	0.9	310	17.2	17.66	17.75	13	2.4	2.3	152
62	2	0.9	241	25.0	24.59	24.67	27	2.2	2.0	152
63	2	0.9	138	10.4	12.35	12.45	61	0.7	0.7	152

Average extinguishment time over all explosive weight with four nozzles at 372-kPa residual pressure: 24 seconds.
Average detection time for above average extinguishment time: 9.6 seconds.

aTime sequence T = 0 at ignition.
bTime from detection to extinguishment.
cDetonated center section, no fire occurred.

Table 9. Maximum side-on overpressures

Stand-off Distance (meters)	Significance	Side-on Overpressure (kPa)
1.52	Closest possible position of deluge riser to explosion	7,584.0
4.82	2nd closest position of deluge riser to explosion	758.0
9.26	3rd closest position of deluge riser to explosion	165.0
37.34	2-psi level	13.8
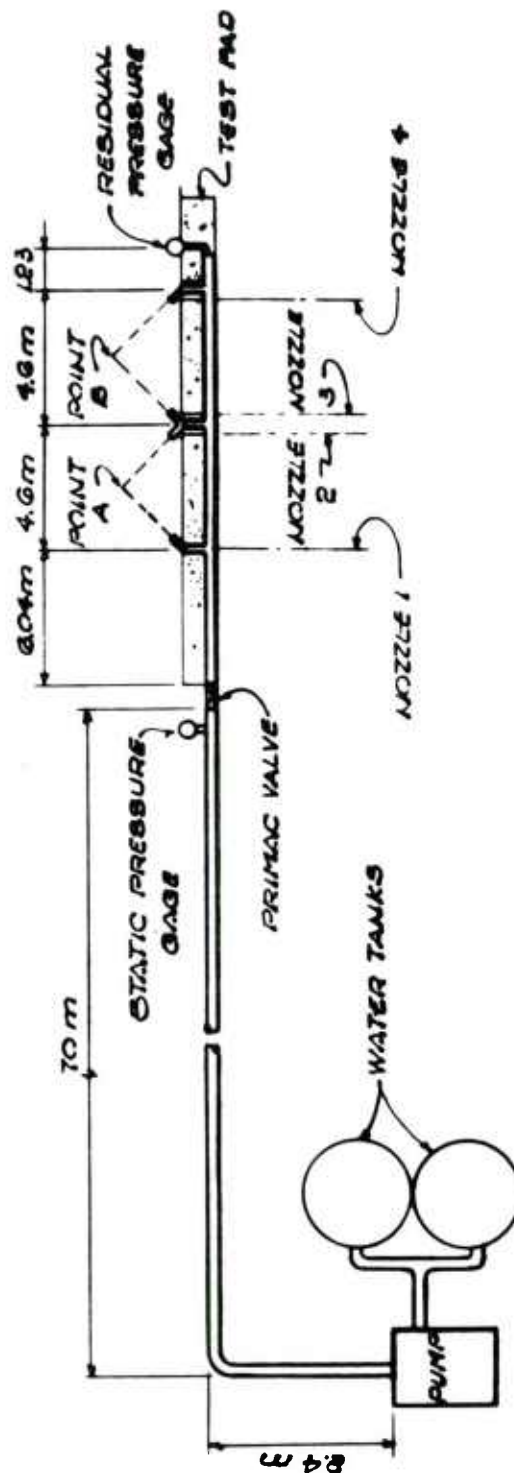
Figure 1. Schematic piping arrangement for tests.

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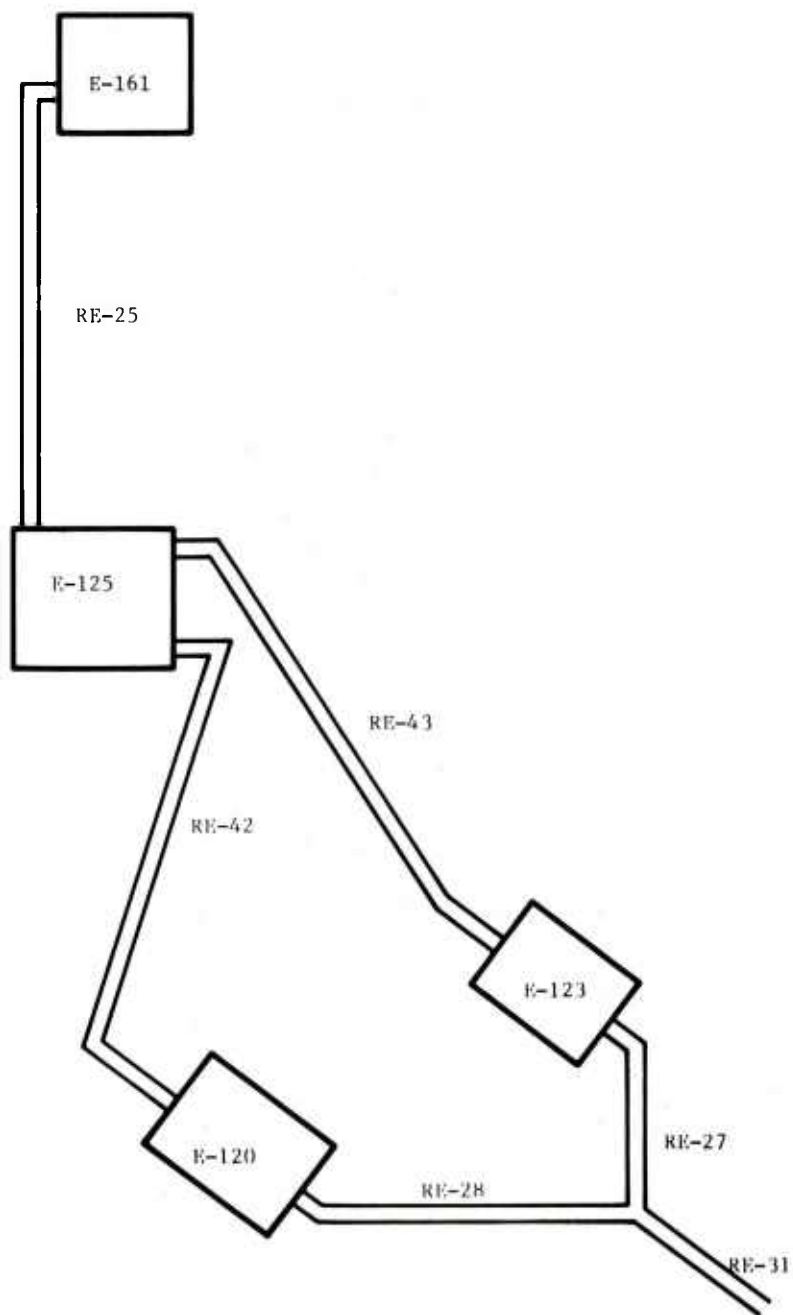
Figure 2.   Schematic of region of interest at
Lone Star AAP (not to scale).
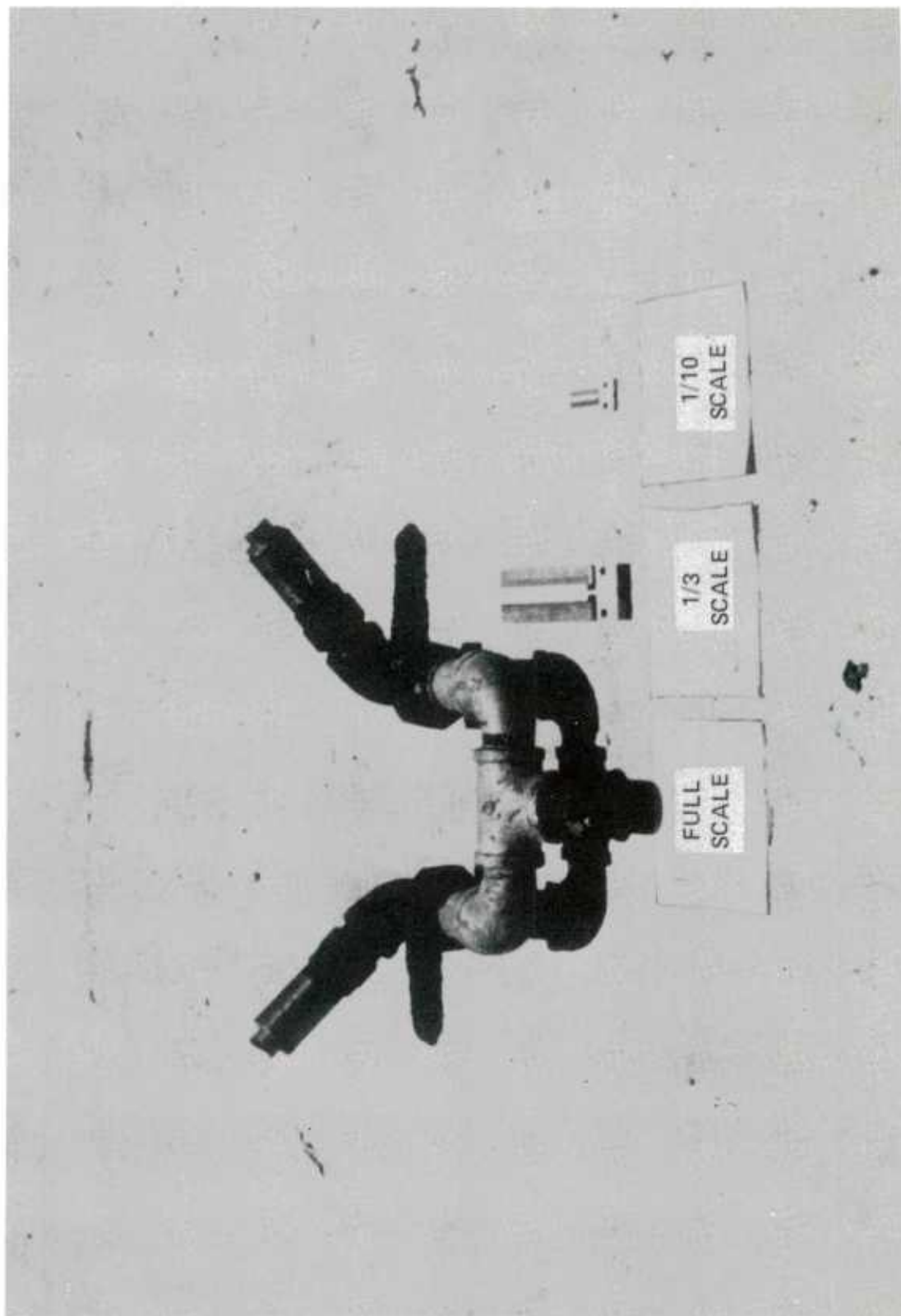
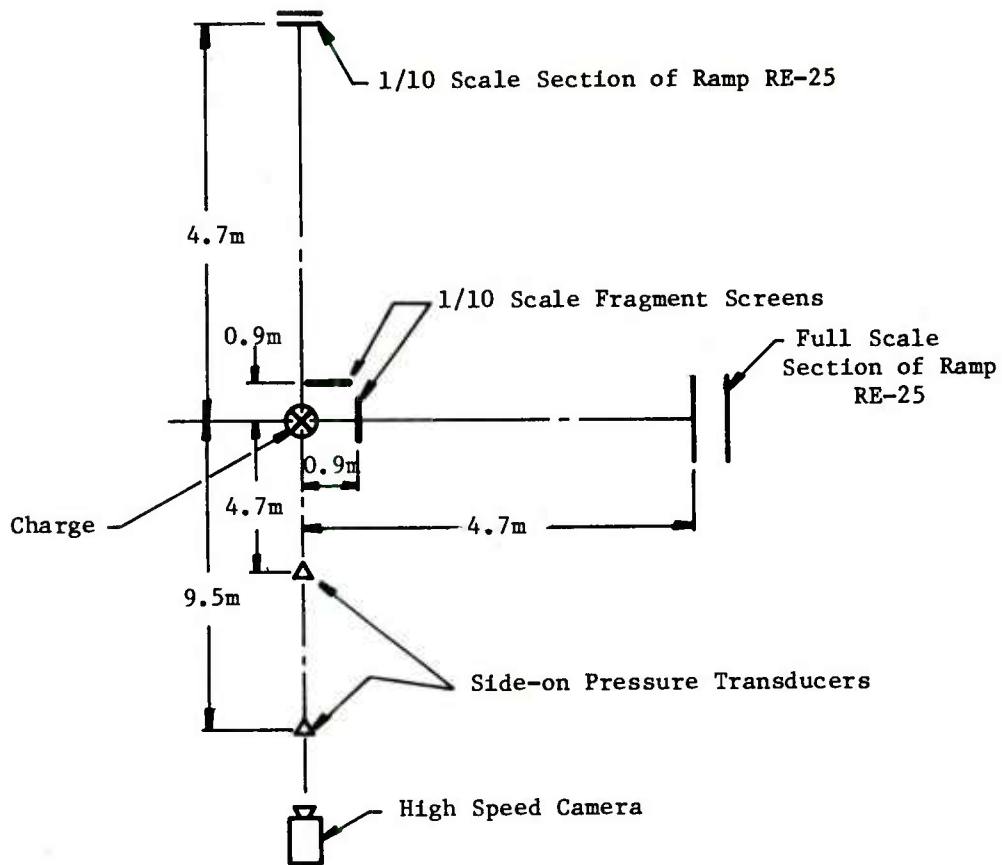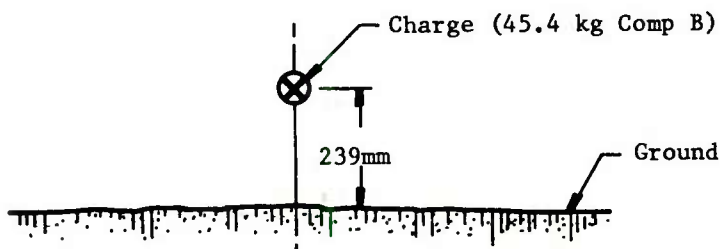Figure 3. Full scale, 1/3 and 1/10 scale model riser nozzle assemblies.

1/10 Scale Section of Ramp RE-25

4.7m

1/10 Scale Fragment Screens

0.9m

Full Scale
Section of Ramp
RE-25

0.9m

Charge

4.7m

4.7m

9.5m

Side-on Pressure Transducers

High Speed Camera

Planview Test 2 setup (not to scale)

Charge (45.4 kg Comp B)

239mm

Ground

Cross section indicating charge height

Figure 4.   Test 2 setup.
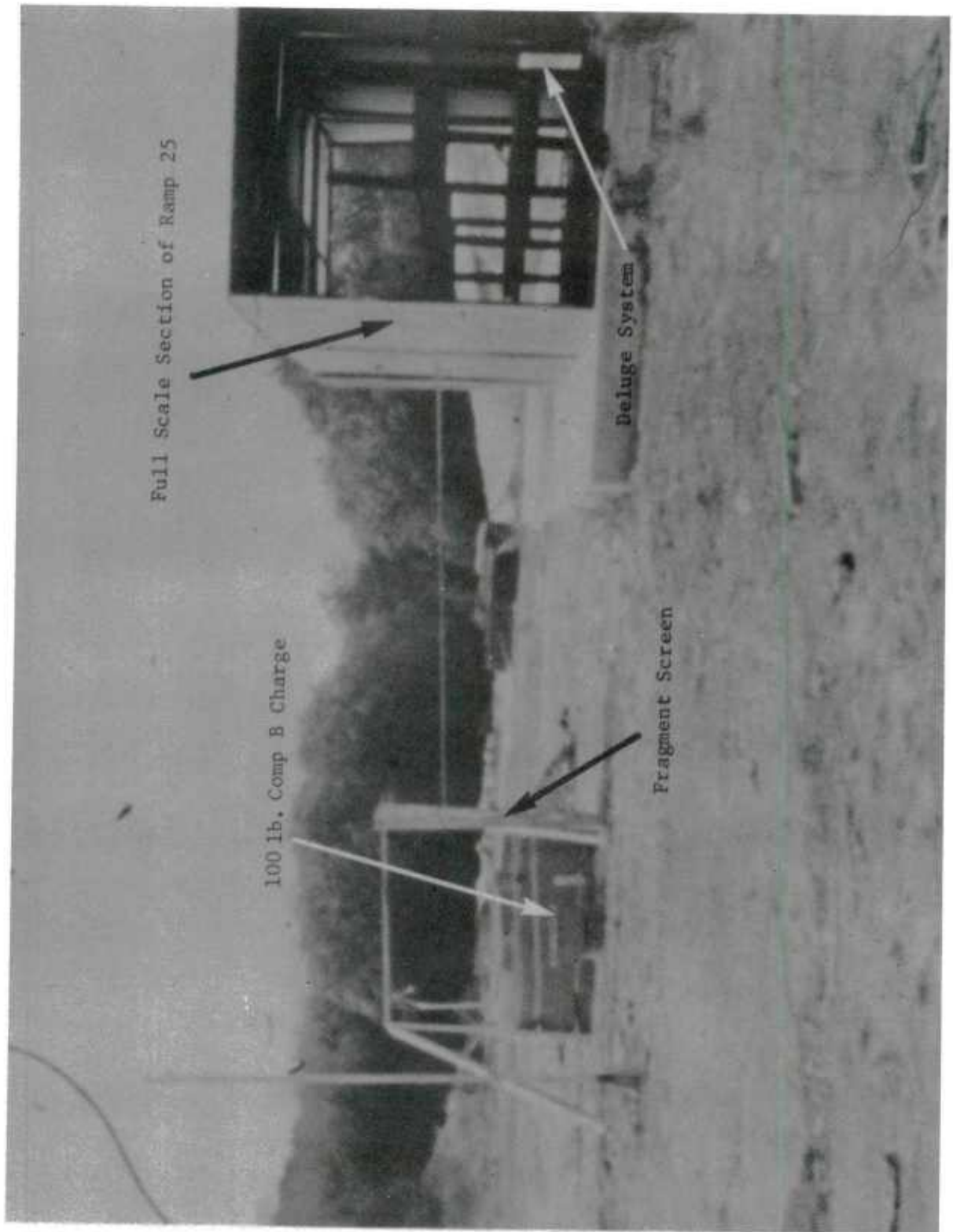
Figure 5. Test 2 setup prior to detonation of 45.4 kg Comp B.

Tunnel Destroyed But
Nozzles Functioning Properly
After Blast

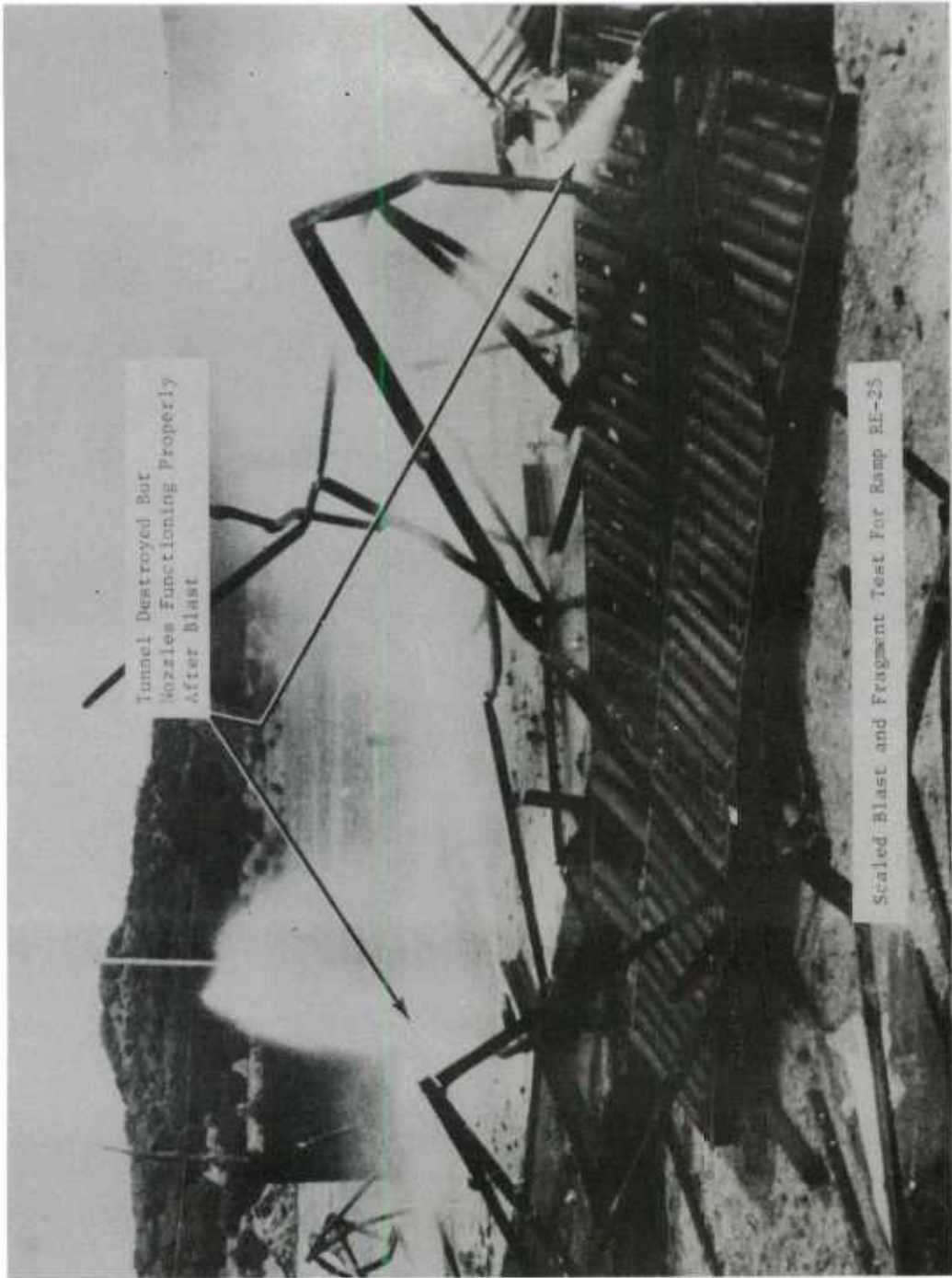Scaled Blast and Fragment Test For Ramp RE-25
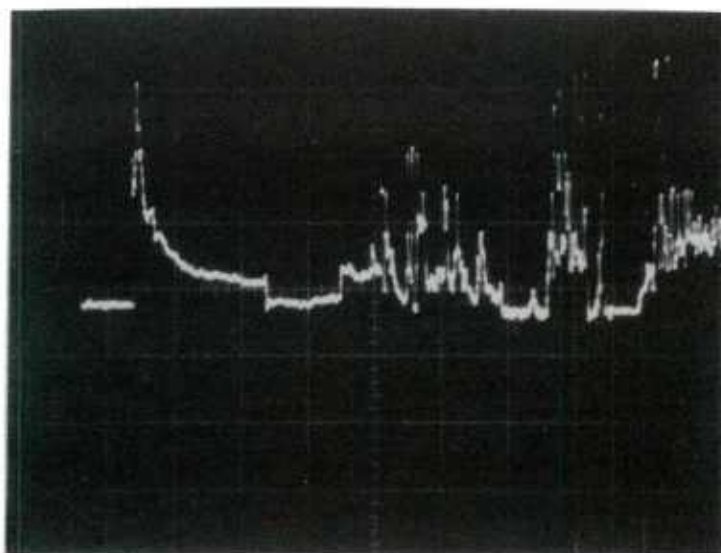
Figure 6. Scaled blast and fragment test for Ramp RE-25.
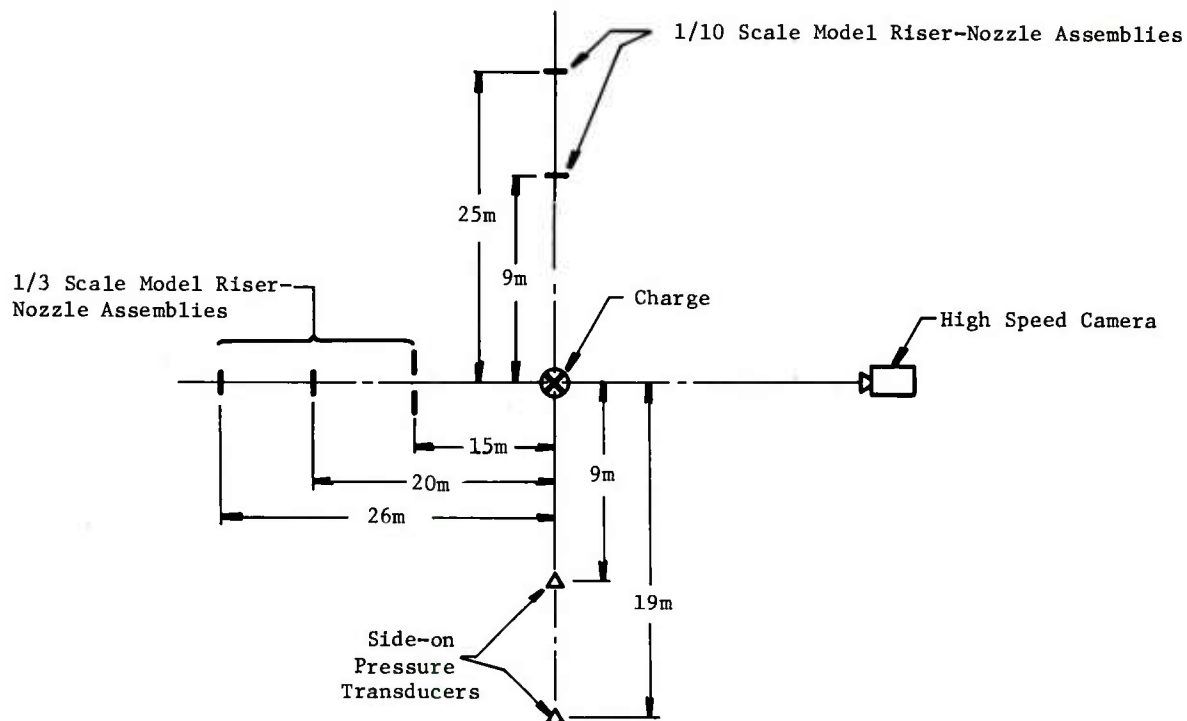
Figure 7.   Destroyed model of section of Ramp RE-25, Test 2.
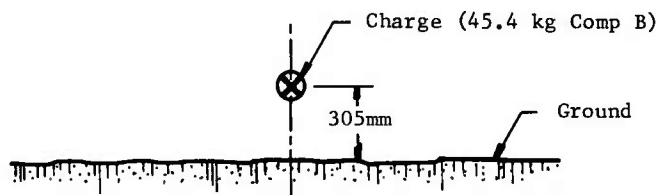

Sweep Rate: 5.0 m sec/
                division
Gain: 1.0 volt/division
Maximum Pressure: 1124
                Kpascals

Time
T = 0

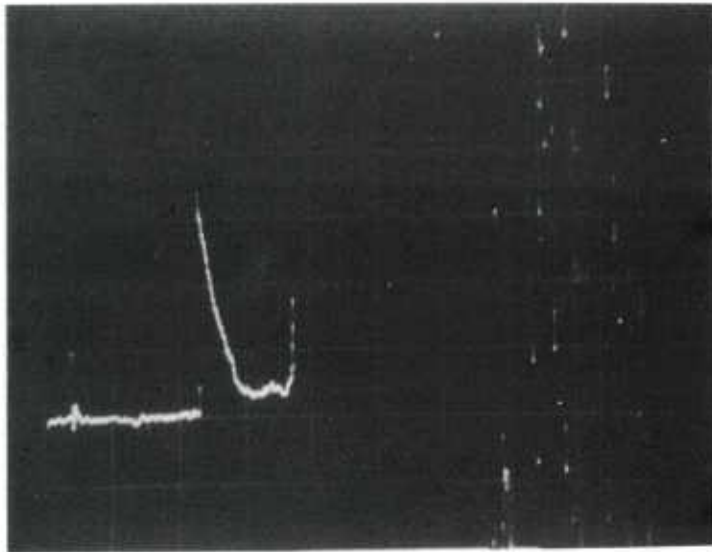Figure 8.   Side-on overpressure history (Test 2, 4.7 m standoff).

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1/10 Scale Model Riser-Nozzle Assemblies

1/3 Scale Model Riser-
Nozzle Assemblies

25m

9m

Charge

High Speed Camera

15m

20m

26m

9m

19m

Side-on
Pressure
Transducers

Planview Test 3 setup (not to scale)

Charge (45.4 kg Comp B)

305mm

Ground

Cross section indicating charge height
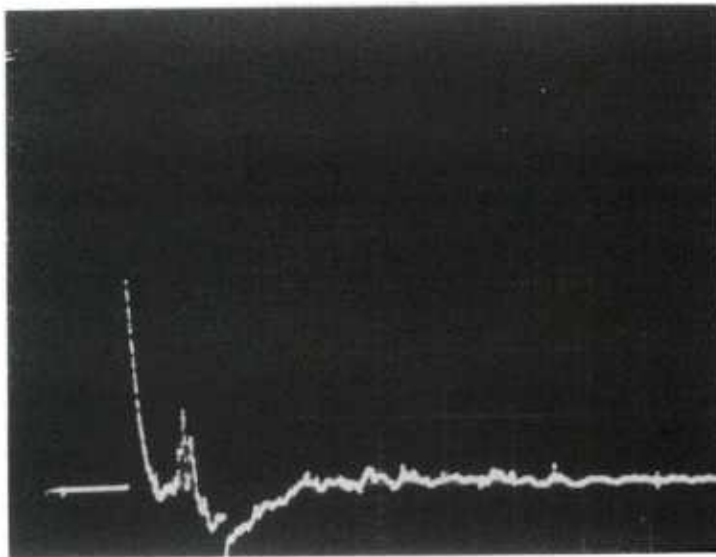
Figure 9.   Test 3 setup.

42

Sweep Rate: 10 m sec/
                     division
Gain: 50 m volts/division
Maximum Pressure: 60
                     Kpascals

Time
T = 0

Figure 10.   Side-on overpressure history (Test 3, 14.6 m standoff).

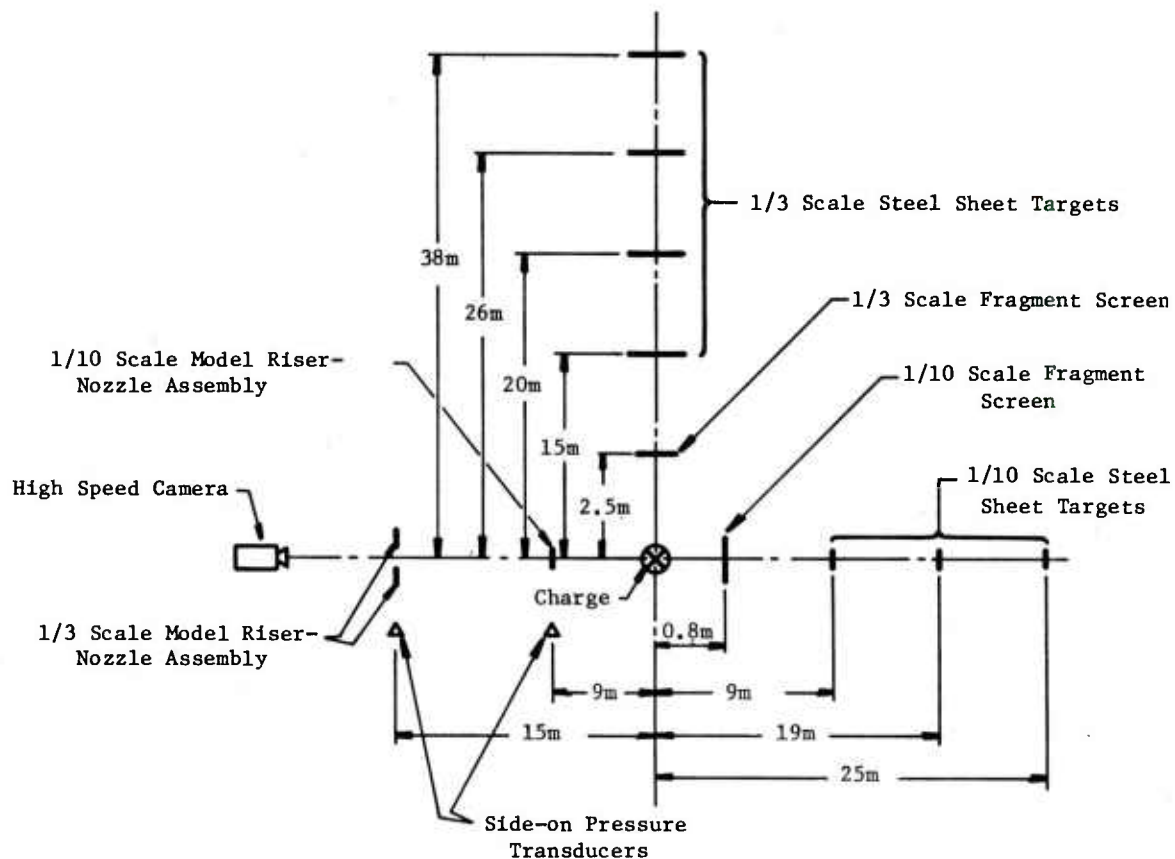Sweep Rate: 1.0 m sec/
                     division
Gain: 50 m volts/
                     division
Maximum Pressure — 43
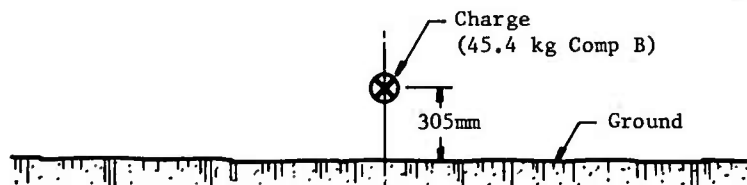   Kpascals

Time
T = 0

Figure 11.   Side-on overpressure history (Test 4, 14.6 m standoff).

Figure 12. Closeup view of 1/3 scale model riser-nozzle assembly after blast (standoff = 26.1 m)

1/3 Scale Steel Sheet Targets

1/3 Scale Fragment Screen

38m

1/10 Scale Fragment Screen

1/10 Scale Model Riser-Nozzle Assembly

26m

20m

1/10 Scale Steel Sheet Targets

15m

High Speed Camera

2.5m

Charge

1/3 Scale Model Riser-Nozzle Assembly

0.8m

9m   9m

15m   19m

25m

Side-on Pressure Transducers

Planview Test 4 setup (not to scale)

Charge
(45.4 kg Comp B)

305mm   Ground

Cross section indicating charge height

Figure 13. Test 4 setup.

45

Explosion of E-161 fragments evaluated at E-123

Test 4 setup

Figure 14. Test 4 results--perforation of steel sheets scaled
to 1/10 riser pipe wall thickness.

Perforation

Explosion of E-161 fragments evaluated at E-125

Perforation

Explosion of E-161 fragments evaluated at junction
of RE-27 and RE-28

Figure 14. Continued

Perforation

Explosion of E-125 fragments evaluated at E-123
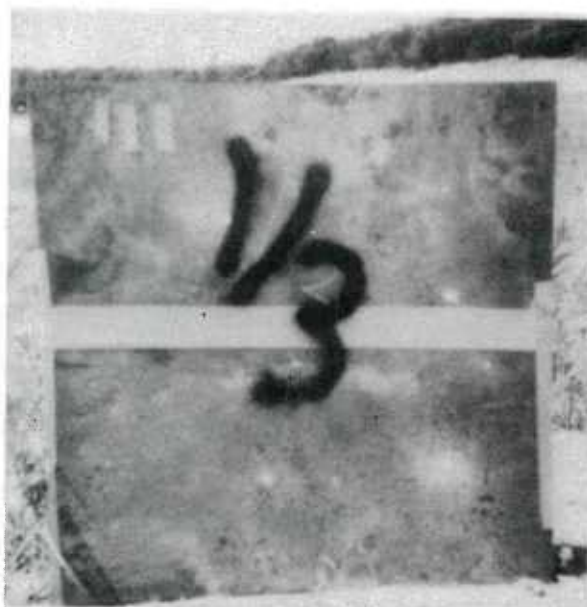
Perforation

Explosion of E-123 fragments evaluated at junction
RE-27 and RE-28

Figure 15. Test 6 results--perforation of steel sheets
scaled to 1/3 riser pipe wall thickness.

Explosion of E-120 fragments evaluated at E-125

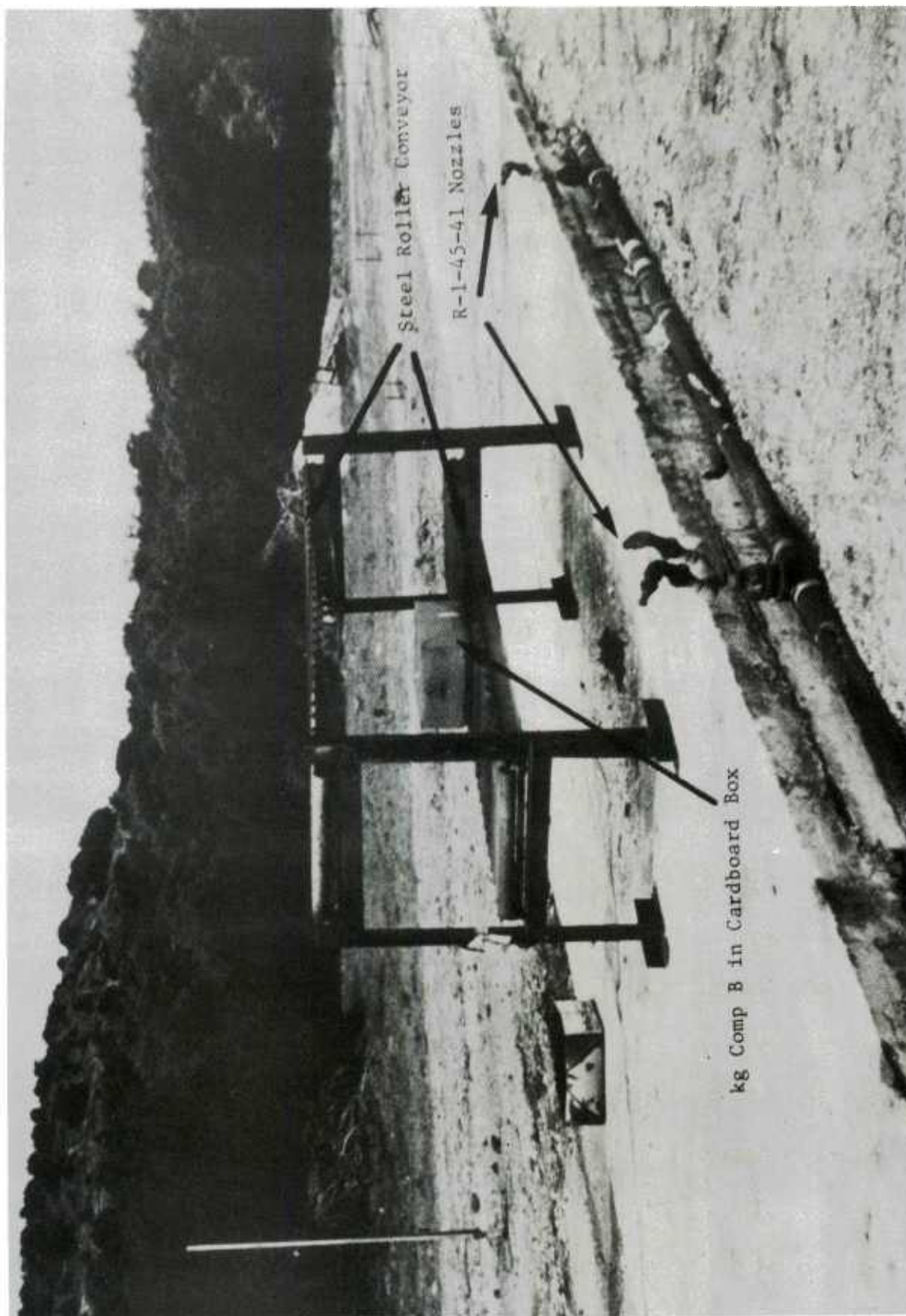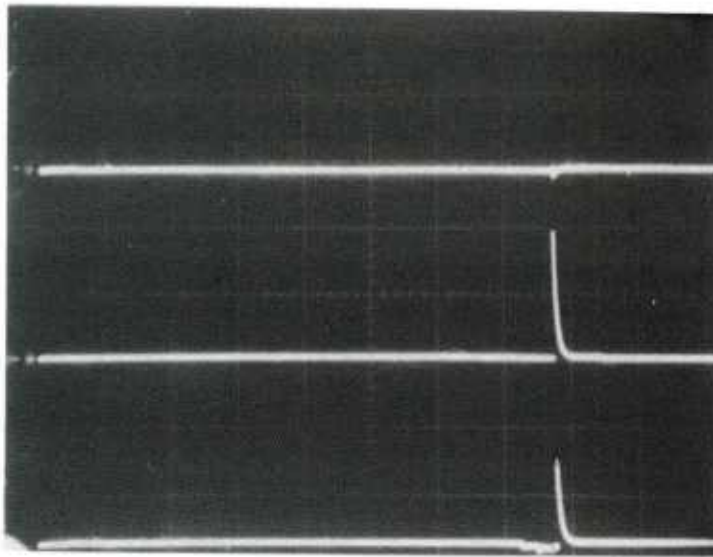Explosion of E-120 fragments evaluated at E-123

Figure 15. Continued

49

Figure 16. Setup for fire extinguishment tests--Ramp RE-25

50

TEST 40

U. V. Detector Signal
1 volt/div

Primac Valve Activation
Signal   10 volts/div

Water on Signal
5 volts/div

Sweep Rate 2 sec/div

Fire test of boxed Comp B simulating RE-25
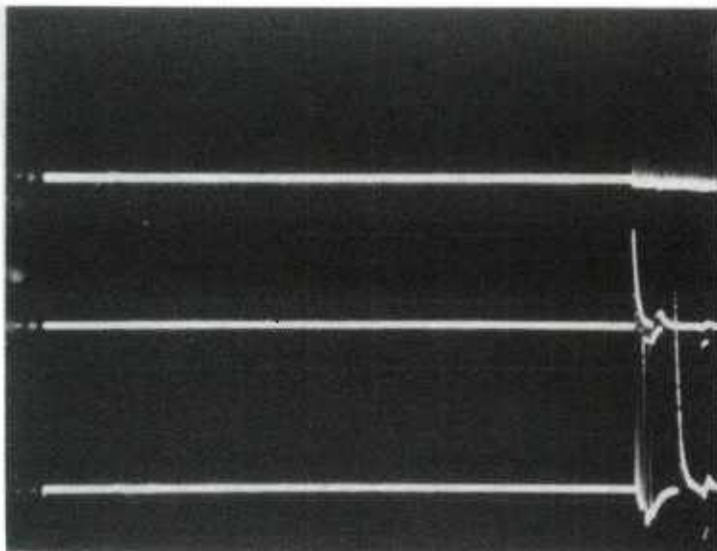

U. V. Detector Signal
1 volt/div

Primac Valve Activation
Signal   10 volts/div

Water on Signal
5 volts/div

Sweep Rate 2 sec/div

Serpentix fire test - Test 51

Figure 17.   Typical response times of water deluge fire
detection and flow activation.

51
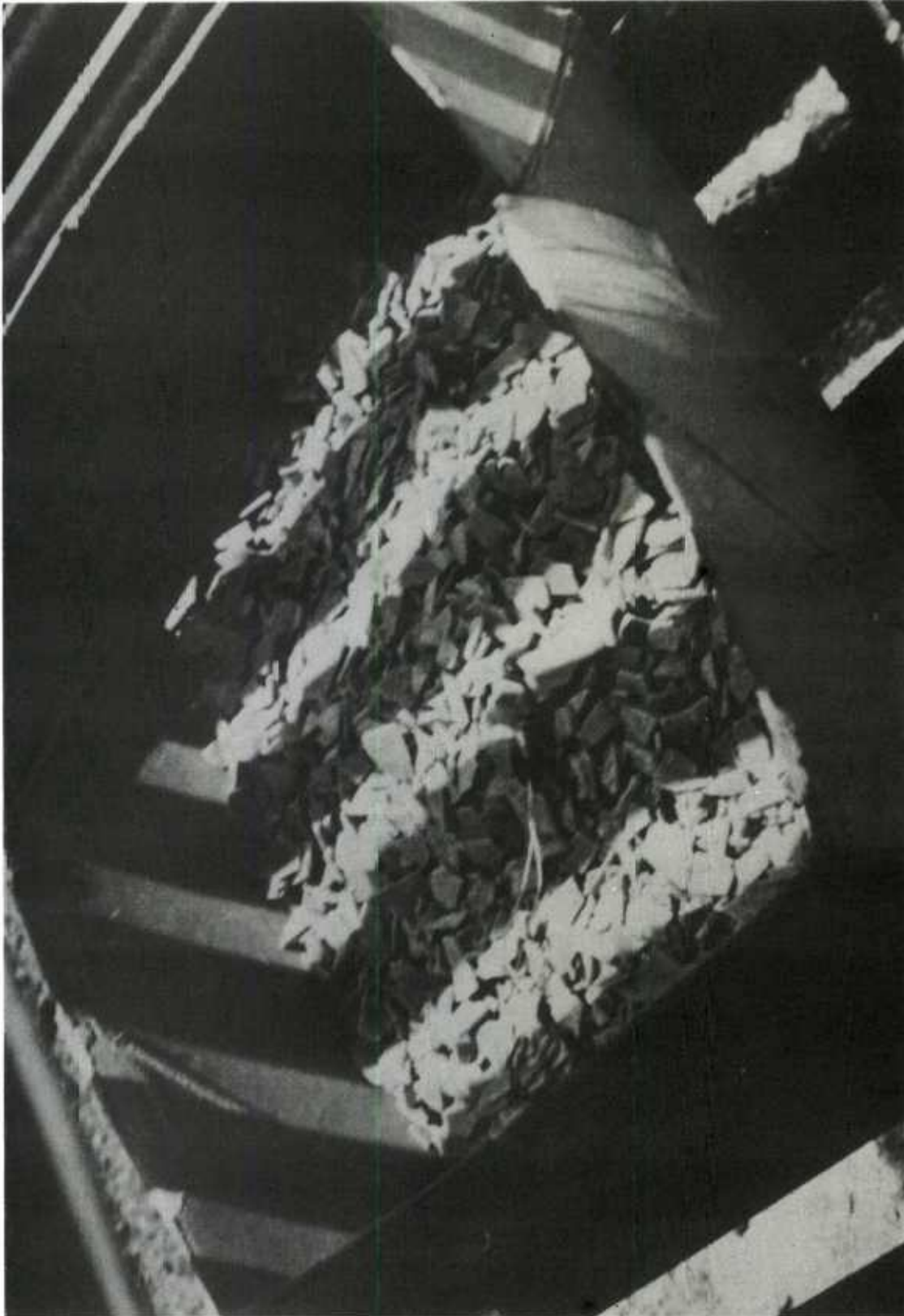
Figure 18. Closeup of Comp B with electric match before test.

Figure 19. Typical residue after successful extinguishment.
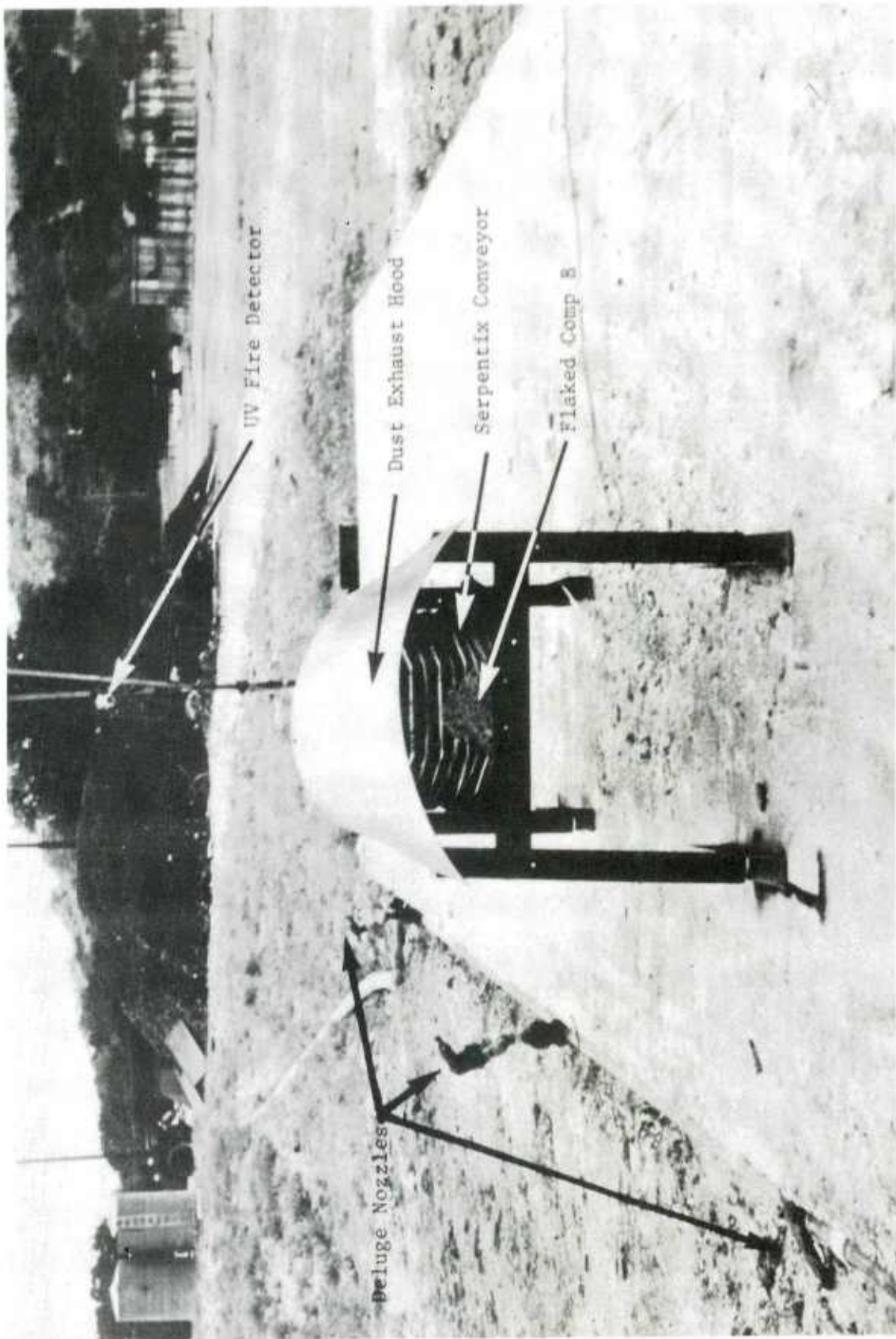
Figure 20. Fire extinguishment tests for Serpentix conveyor (Ramps RE-42/RE-43).

Dust Exhaust Hood

Electric Match

Comp B

Serpentix Conveyor
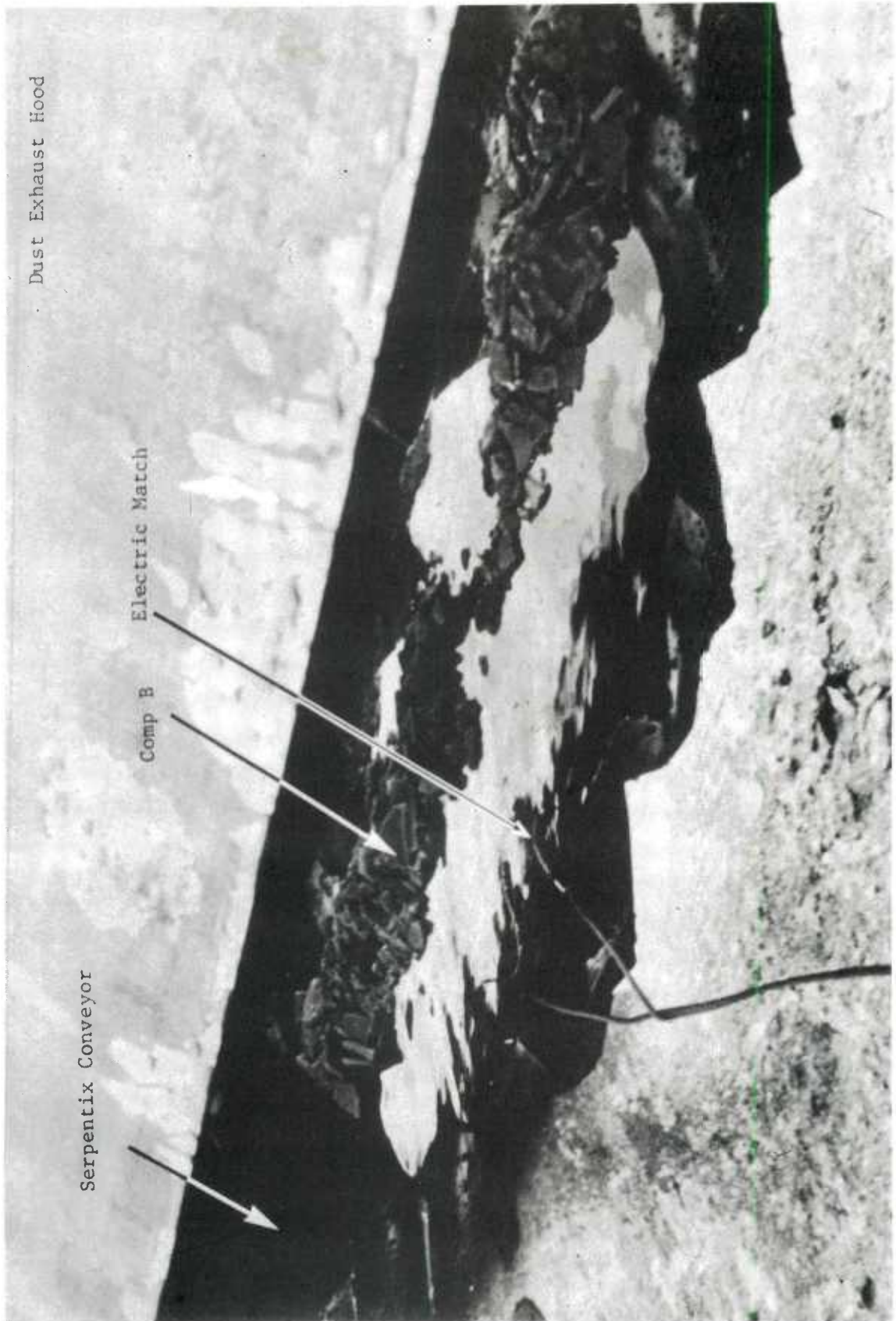
Figure 21. Successful extinguishment of Comp B fire on section of Serpentix conveyor.

55

Figure 22. Exposed feeder pipe inside Ramp RE-25 after explosion of 27.2 kg Comp B in carboard box on steel roller conveyor.
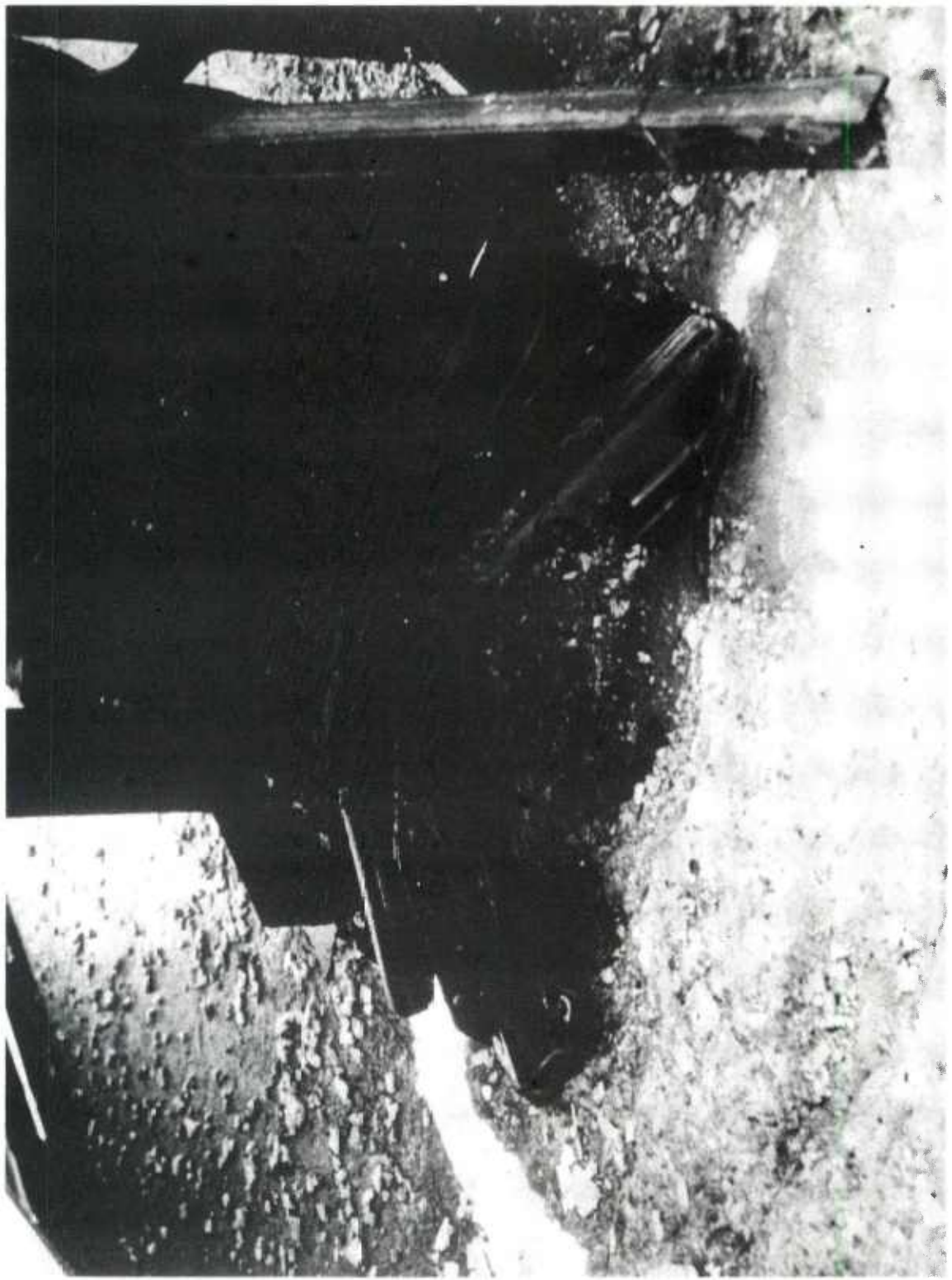
Figure 23. Test 70--detonation of single pan of Comp B on Serpendix conveyor without propagation to adjacent pans.

57
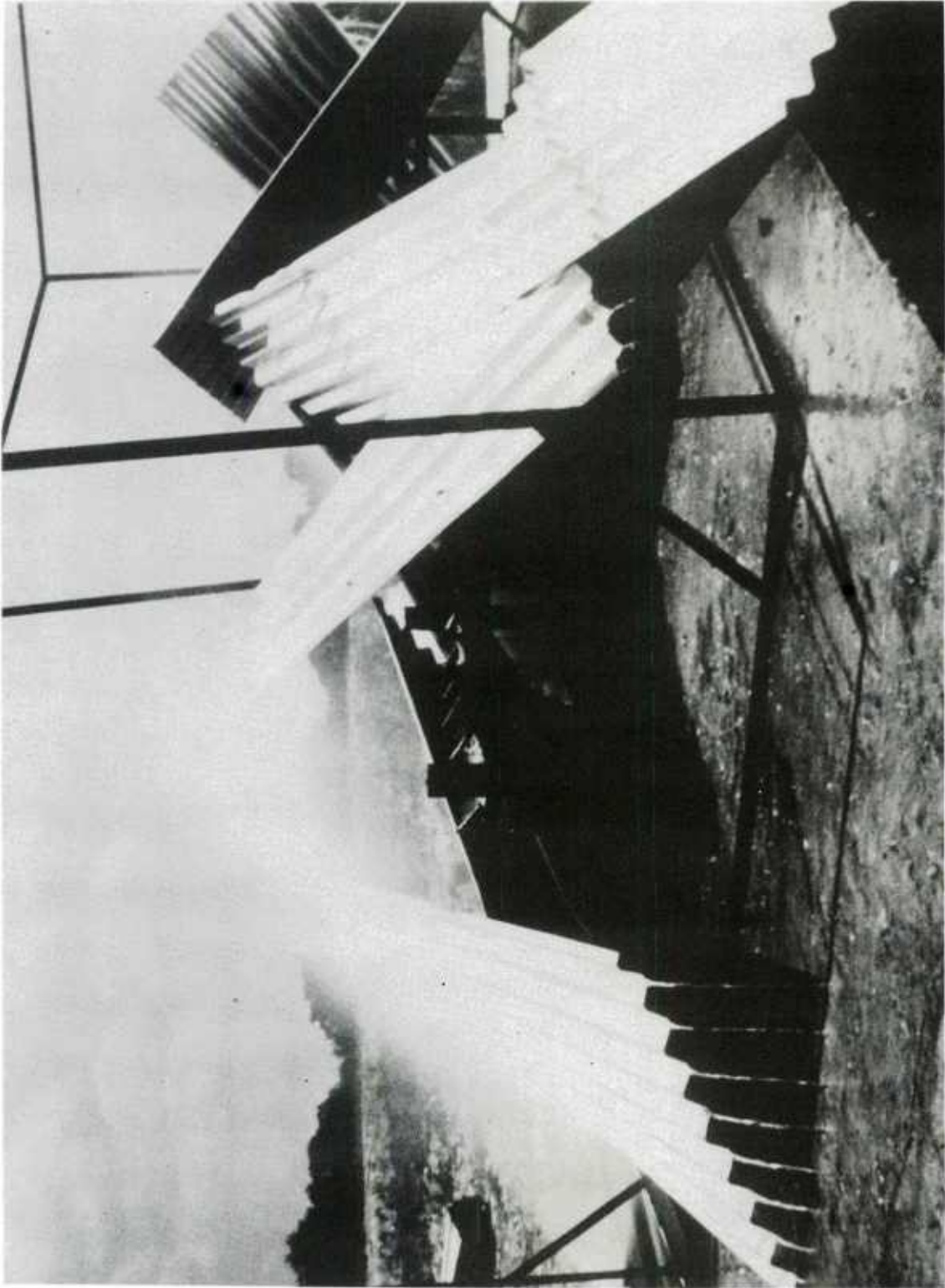
Figure 24. Overall view--Test 70.

58
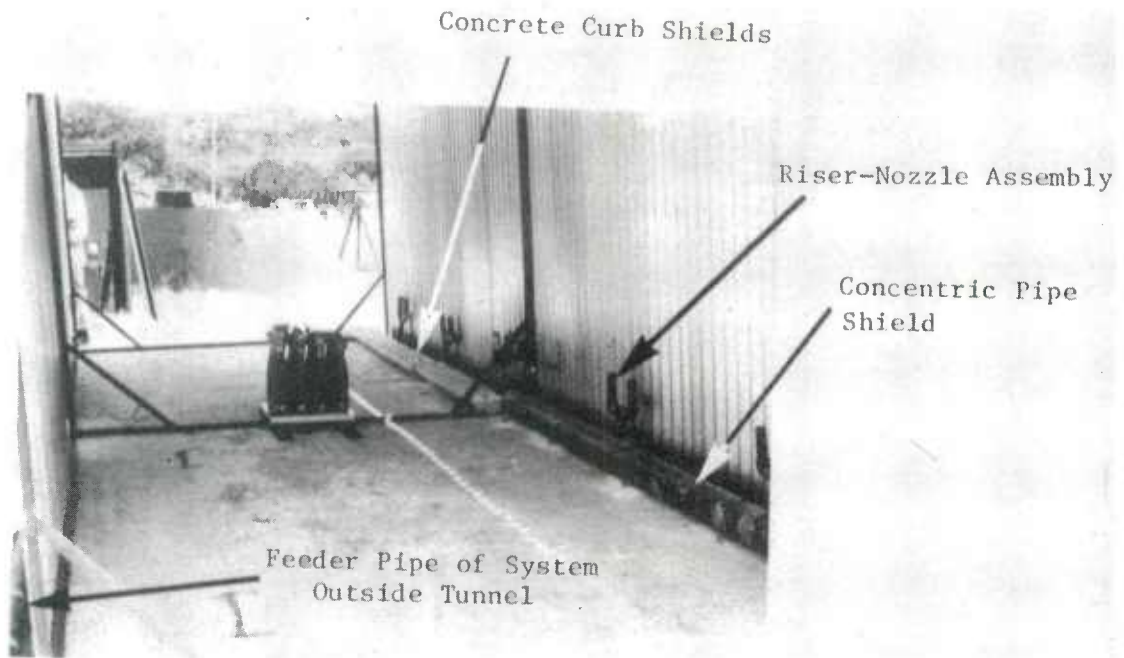
Figure 25. Test setup--Test 71.

Figure 26. Overview of damage--Test 71.

Figure 27. System with concrete curb shields after test.

Figure 28. UV detector after test (still functional).
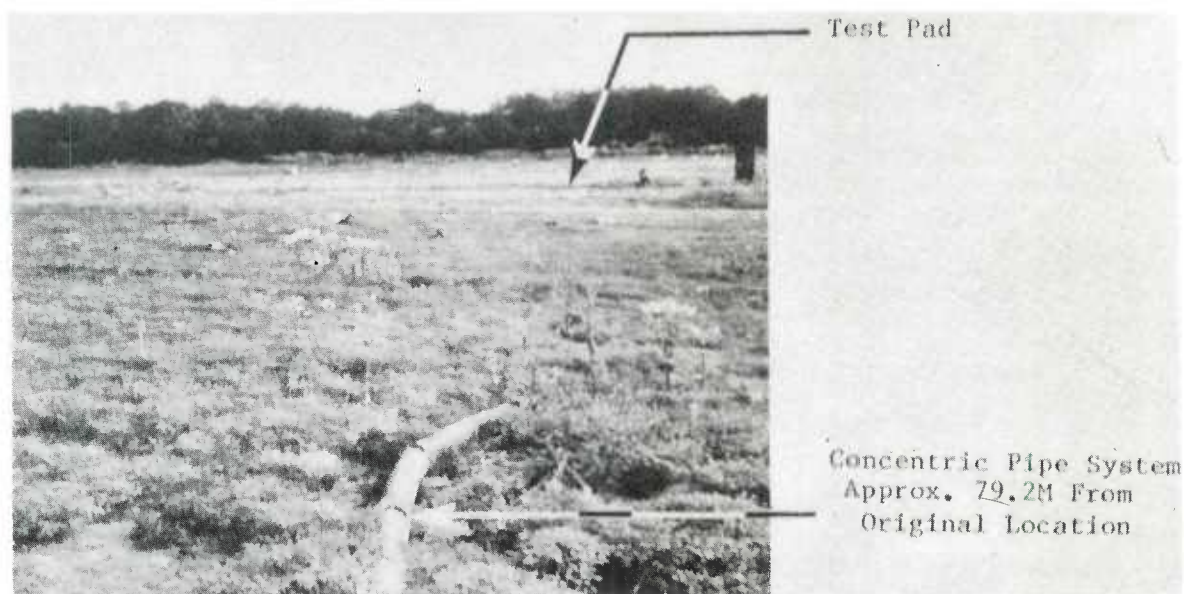
Figure 29.   Location of concentric pipe system after test.
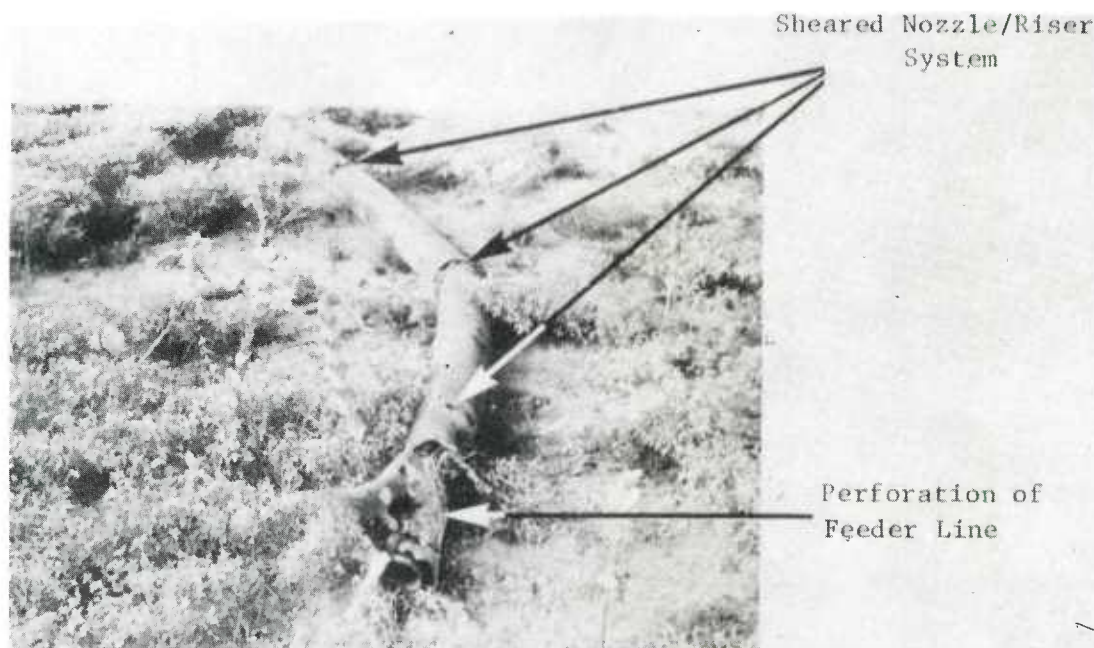
Figure 30.   Closeup of concentric pipe system after test.

61

Riser/Nozzle
Assembly Sheared

Feeder Pipe Intact
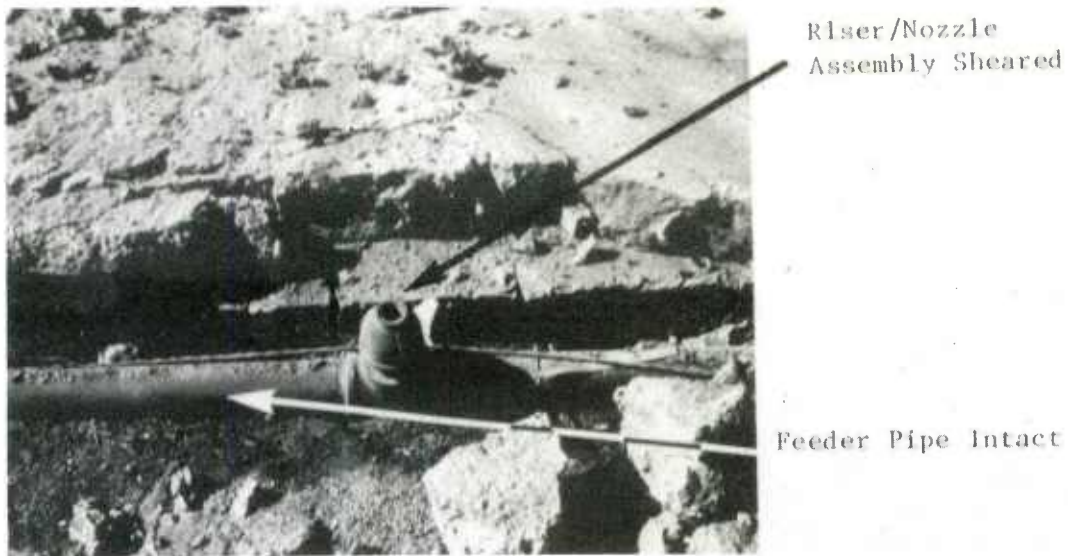
Figure 31.   Deluge system shielded by concret slab
(underground system)

Recovered R-1-45-41
Nozzle
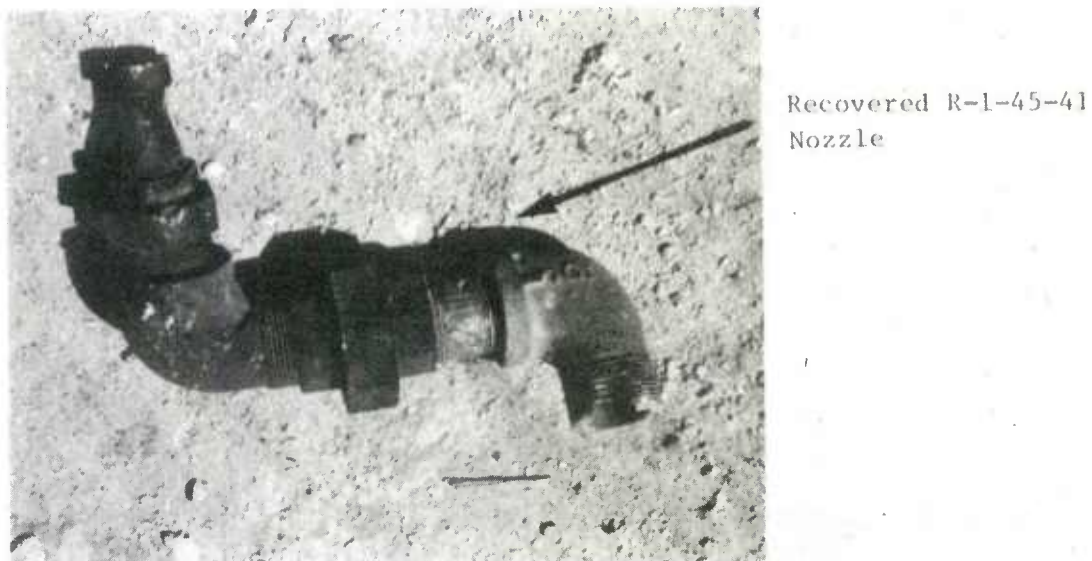
Figure 32.   Recovered R-1-45-41 nozzle.

No. of Hits

3	20	17	Avg. = 13 Total = 40
2	29	26	Avg. = 19 Total = 57
6	23	22	Avg. = 17 Total = 51
4	31	35	Avg. = 23 Total = 70

Each section is
0.61 m x 0.61 m

Avg. = 4
Total = 15

Avg. = 26
Total = 103

Avg. = 25
Total = 100

Shield

12.2 m

Projectile

Total Hits = 128

Average Depth =   7.06 mm

Deepest Depth =   20.32 mm

Shallowest Depth = 0.25 mm
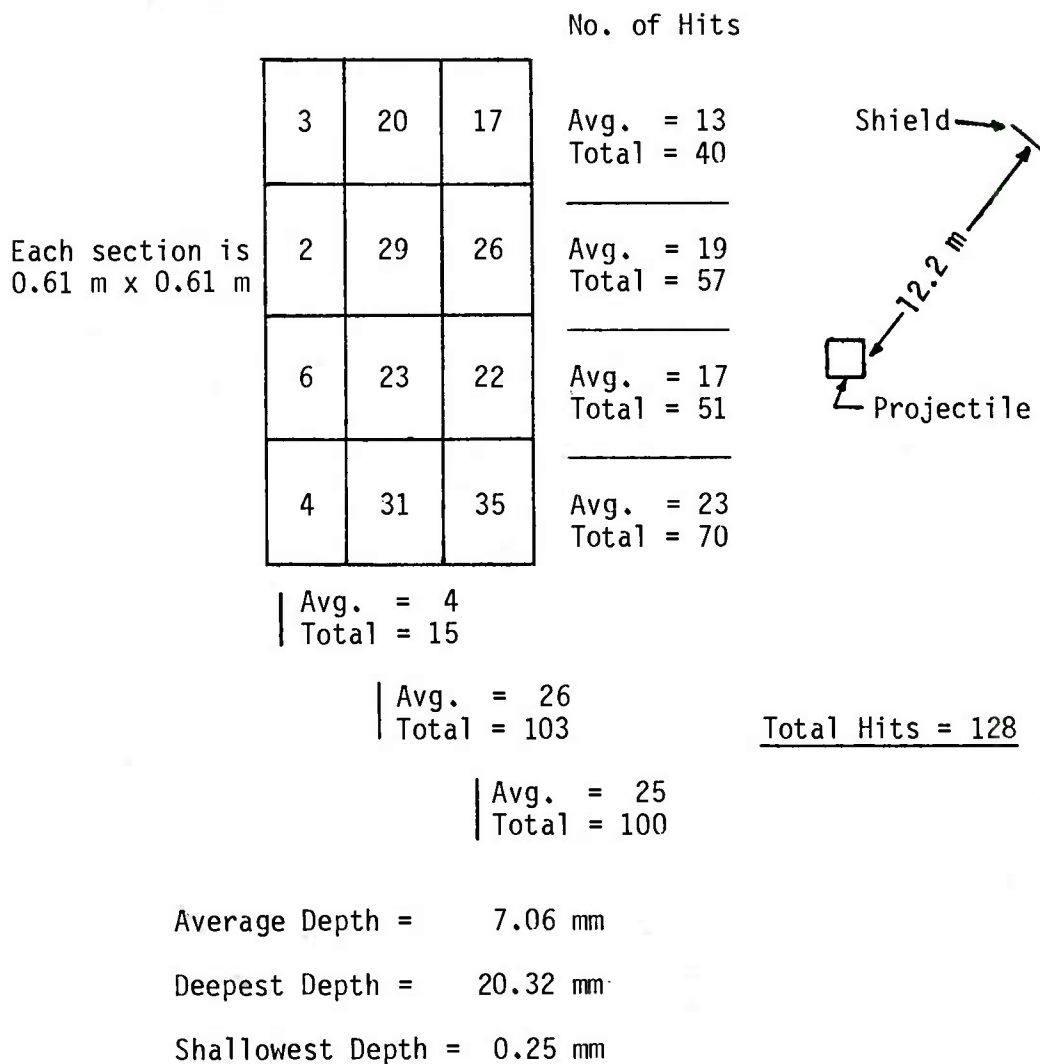
Figure 33.   Fragment distribution.

63
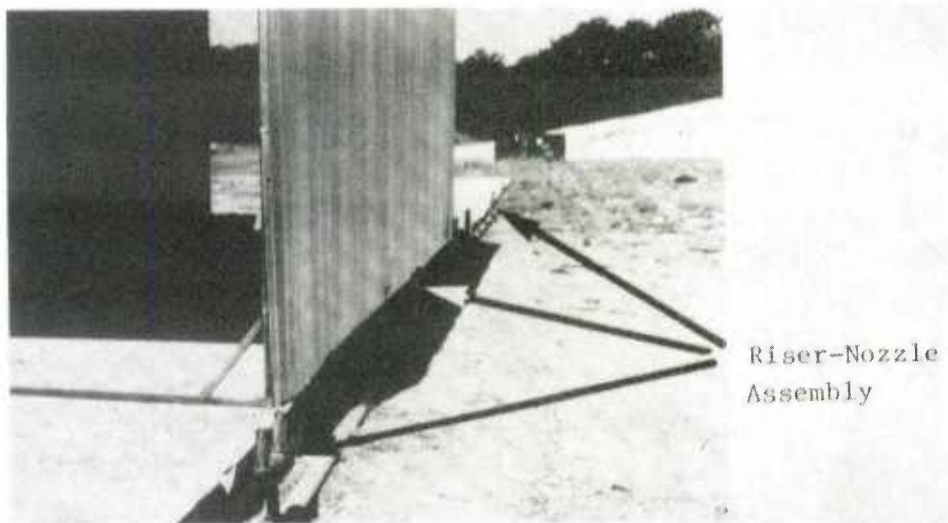
Figure 34.   Test 72 setup.
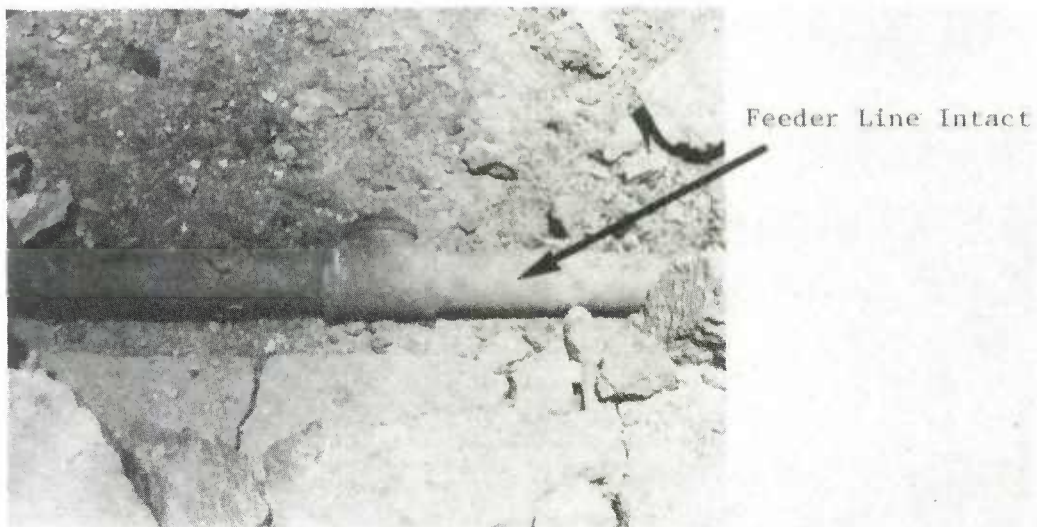
Figure 35.   Riser-nozzle assembly at 1.5 m standoff.
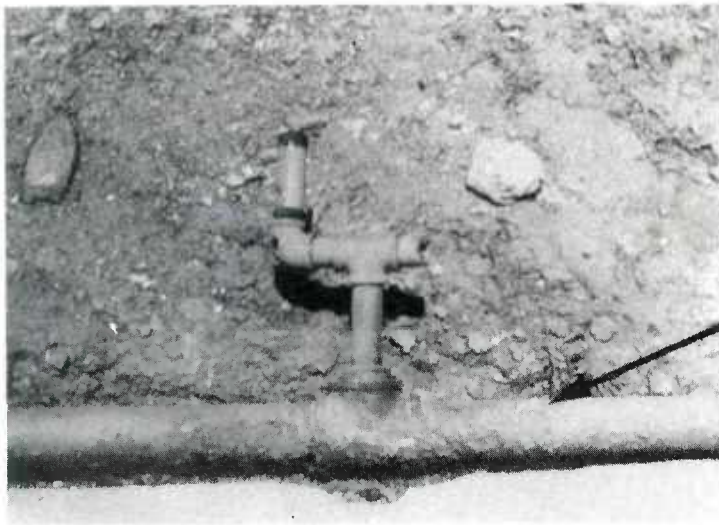
Feeder Pipe Intact

Figure 36.   Riser-nozzle assembly 3.6 m standoff.
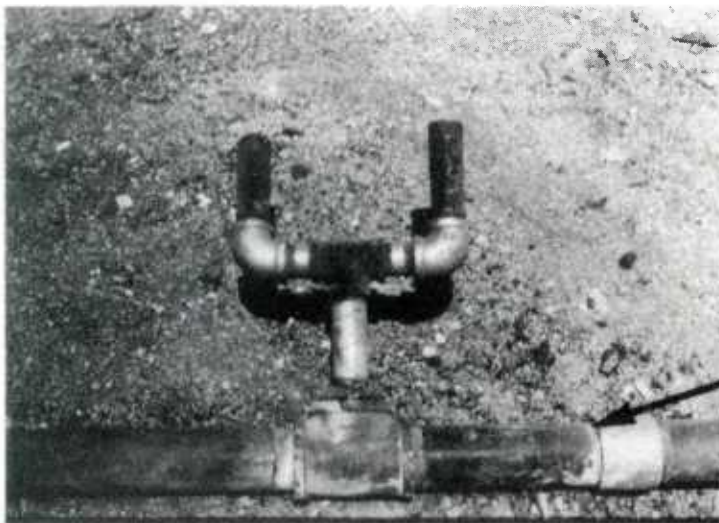
Feeder Pipe Intact

Figure 37.   Riser-nozzle assembly 10.1 m standoff.

65

Feeder Pipe Intact

Figure 38. Riser-nozzle assembly at 13.2 m standoff.
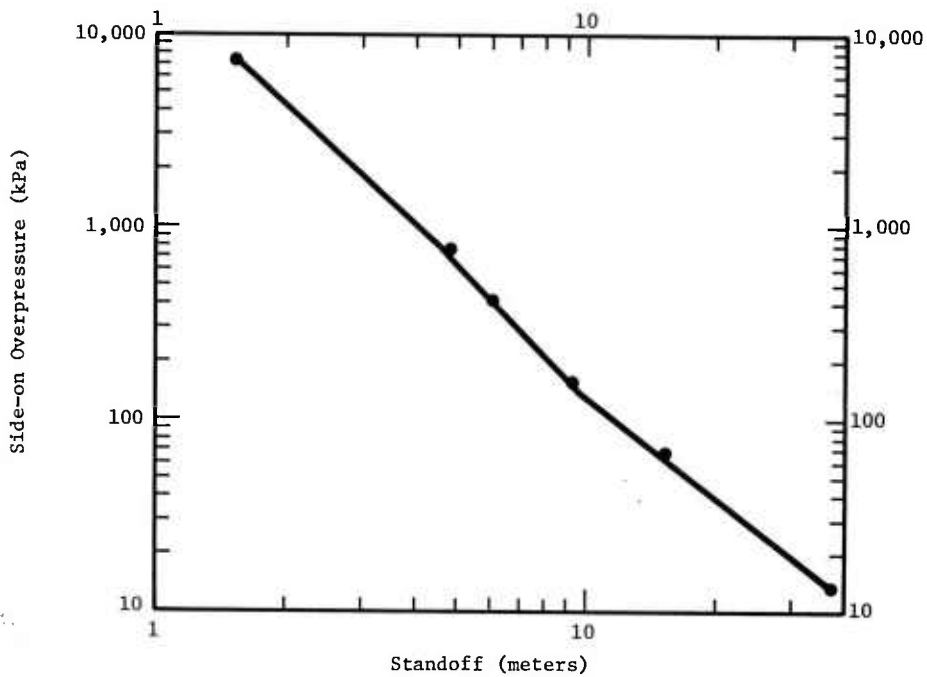
Figure 39. Side-on overpressure vs. standoff for 45.4 kg Comp B.

APPENDIX A.   SCALE MODELS OF SPRAY-NOZZLE ASSEMBLY

NO.5 (.2055) DRILL
2 HOLES

.151 (REF)

.151 ±.002 60°

.1273 ±.003

SECT. B-B

.56

1.00

.312

.625

.31

BOTTOM

125

.125 ±.005

B

MIN R

B

A

.256 ±.003

.512 ±.005

SECT A-A

.0755 ±.002

.151

.043

.054

.180 5

.151

A

NOTE: TWICE SIZE
CENTER DRILL ON TOP END IF REQ'D.

LET.	CHANGE	DATE	BY	APP.	DASH NO.	NO. REQ'D	PART NAME		MATERIAL
	REVISIONS						PARTS LIST		

DRAWN BY
L.R.G.

NO REQ'D

TOLERANCES UNLESS NOTED
DECIMALS .XX ±.005
DECIMALS .XX ±.010
FRACTIONS ±
ANGLES ±

DESIGNED BY
L.R. GARZA

MATERIAL HR S
ASTM A 306 GRADE 5

1/10 SCALE MODEL - SPRAY NOZZLE ASSY.

CHECKED BY

HEAT TREAT

SOUTHWEST RESEARCH INSTITUTE
SAN ANTONIO, TEXAS

DATE 3·30·78   SCALE 2:1

APPROVED BY

FINISH 125√

DRAWING NUMBER A-02·5157-02

CENTER DRILL PERMISSIBLE

SECT A-A

SECT. B-B

TOL. ± .002

17/64 DRILL 2-HOLES

MIN. R.

.33 SCALE MODEL - SPRAY ASSY.

					PARTS LIST	MATERIAL
DASH NO.	NO. REQ'D.			PART NAME		

LET.	CHANGE	DATE	BY	APP.
	REVISIONS			

TOLERANCES UNLESS NOTED
DECIMALS .XXX ± .005
.XX ± .01
FRACTIONS .XX ± .01
ANGLES

DRAWN BY	L.R. GARZA	NO. REQ'D.
DESIGNED BY	L.R. GARZA	MATERIAL HRS ASTM A306 GRADE 5
CHECKED BY		HEAT TREAT —
APPROVED BY		FINISH —

SOUTHWEST RESEARCH INSTITUTE
SAN ANTONIO, TEXAS

DATE 3-29-78	SCALE FULL
DRAWING NUMBER	A-0C-5157-01

APPENDIX B.   EQUIPMENT LIST

APPENDIX B. EQUIPMENT LIST

The following is a list of components used in the water deluge system for experiments conducted in support of the 105-mm melt/pour project:

Equipment	Manufacturer	Purchased From
Water pump, Hale Model 50FB2-C225, gas-powered	Hale Fire Pump Company Conshohocken, Pa. 19428	Simms Fire Equipment Co., Inc. 127 McCullough San Antonio, Texas 78298
Supervised Ultra-violet Fire System: DE-R7300A Controller C7037B Detector DE-Q9001A Swivel Mount	Detector Electronics Corporation 7351 Washington Avenue, South Minneapolis, Minn. 55435	Detector Electronics Corporation 7351 Washington Avenue, South Minnespolis, Minn. 55435
Primac Valve B-2 Mulsifyre R-1-45-41-RD	Grinnell Fire Protection Systems Co., Inc. 10 Dorrance Street Providence, RI 02903	Grinnel Co., Inc. 161 Glass Street Dallas, Texas 75207
3-inch I Galvanized Pipe	-	Esco Supply 1234 San Francisco San Antonio, Texas 78298

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